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LANDSAT MSS DIGITAL DATA FOR PEATLAND INVENTORY

by

CLAUDIA L. PALYLYK

(C)

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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ABSTRACT

This study was designed to determine the degree to which LANDSAT MSS digital data can be applied to a peatland inventory in the Boreal Wetland region of Alberta.

LANDSAT-2 MSS digital data from 12 May 1981 and 15 September 1981 were obtained for the Athabasca-Calling Lake region. Image enhancement, unsupervised classification and supervised classification were applied to single date and multidate data.

Enhanced color composite images were produced using piece-wise stretched data. Multidate color composites provided optimal contrast of cover types for stratification of peatlands. For delineation of broad cover classes, May imagery was more effective than September imagery.

Unsupervised classification was applied to single and multidate data. In an attempt to bias classification towards peatlands, three combinations of spectral band limits and source areas were used in signature generation. Of the resultant themes, few were specific to peatlands alone, with most being representative of both peatland and upland cover types. May data produced the greatest number of spectral classes associated with indigenous cover types, relative to either the September or multidate data.

Supervised classification involved generation of single date and multidate spectral signatures for five peatland types: Treed Fens, Lightly Treed Fens, Shrubby Fens, Sedge Fens and Forested Bogs. Multidate signatures were more

discriminating than single date signatures for these peatland types.

On resultant thematic maps, Forested Bogs and Sedge Fens were most often correctly represented in accordance with the Peatland Inventory Field Maps used as verification data. Fens were observed to be highly variable in their spectral and spatial characteristics. This variability was recognized in the Peatland Inventory map unit concepts, but could not be incorporated fully into the respective spectral signatures.

The heterogeneity of vegetation cover associated with peatlands and uplands contributed to the spectral complexity of the region. This inherent complexity limited the utility of the supervised and unsupervised classification procedures applied.

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1. INTRODUCTION

Current estimates indicate that approximately 160,000 km^2 of peatlands occur in the Boreal Wetland Region of Alberta, north of the prairie zone (Zoltai and Johnson 1983).

Land resource inventories of this region, in the form of Soil Survey, Forest Inventory and Ecological Land Classification maps, generally do not provide sufficiently detailed information on the location, type, composition and areal extent of peatlands, as required by various private and government agencies interested in peatland inventory.

A renewed interest in Alberta's peatlands for purposes of integrated resource management led to the initiation of the Peatland Inventory Pilot Project in 1983, as a joint effort involving the Resource Evaluation Branch of Alberta Energy and Natural Resources and the Terrain Sciences Department of the Alberta Research Council. The information to be acquired during this pilot project exceeded that currently available, especially in terms of the areal extent, associated soils and vegetation, and chemical and physical characteristics of peat deposits in the Athabasca-Calling Lake region of Alberta.

Site specific information on chemical and physical characteristics of peatlands may be obtained only through intensive field sampling. Information on areal extent and associated vegetation cover, however, may be obtained on a more generalized level through reconnaissance surveys.

LANDSAT satellite Multispectral Scanner (MSS) data provide synoptic coverage of the earth's surface in four spectral bands for 79 m x 79 m resolution cells. These data, in the form of computer-compatable tapes, facilitate multispectral and multidate analysis of a variety of terrain features. In addition, LANDSAT MSS data provide an information base for large area reconnaissance, especially useful in regions that are not easily accessed.

Recent Canadian literature cited in the next chapter has indicated that LANDSAT MSS data may be used to identify peatlands on the basis of spectral reflectance characteristics of their associated ground cover. Furthermore, identification of specific ground cover types has been extrapolated to infer specific characteristics of the underlying peat deposits. This procedure requires the existence of strong, direct and consistent relationships between the reflectance characteristics of the vegetation cover (i.e. indicator species) and the characteristics of underlying peat deposits. Should these inferences be applicable within the Boreal Wetland Zone of Alberta, analysis of LANDSAT MSS data could provide a valuable method of augmenting traditional field surveys and aerial photo interpretation for peatland inventory.

The purpose of this study was to determine the degree to which LANDSAT MSS digital data can be applied to a peatland inventory in the Boreal Wetland region of Alberta.

The objectives of the study were:

1. To determine the spectral separability of indigenous peatland types through application of three methods of computer-aided LANDSAT MSS digital data analysis (image enhancement, unsupervised classification and supervised classification) to single and multidate data.

2. To determine the potential for signature extension.

3. To determine the compatibility of the results of LANDSAT MSS data analysis with existing peatland classification systems.

2. LITERATURE REVIEW

The following discussion is structured according to three major subject areas. Firstly, a brief introduction and discussion of Boreal Peatlands and historically applied inventory methodology is presented. Secondly, the characteristics of LANDSAT MSS digital data and general analysis procedures are discussed. The application of these analysis procedures to wildland inventories with emphasis on wetlands and peatlands in the Canadian environment constitutes the third section.

2.1 PEATLANDS

The literature abounds with definitions of peatlands that range from very generalized descriptions to complex taxonomic terminology. The application of these definitions to the Boreal Region of Canada, and specifically to Alberta, requires that the characteristics of peatlands indigenous to these regions be considered.

Moore and Bellamy (1974) provide a generalized definition of peatlands that encompasses the vegetational, hydrological and environmental changes that initiate the developmental and successional processes involved in the formation of peatlands. Their definition is presented as follows:

> "Peatlands are, by defintion, unbalanced sytems in which the rate of production of organic material by living organisms exceeds the rate at which these compounds are respired and degraded. The result is an accumulation of a proportion of this production as an organic deposit which is termed "peat". As a peat blanket thickens, the surface vegetation becomes insulated from underlying soils and rocks, and the resulting environmental changes are often accompanied by floristic changes which reflect the altered hydrology and chemistry of the peat surface. Peat producing ecosystems, or mires, thus are dynamic ecological entities, constantly changing, growing, spreading and eroding."

Concepts and definitions based on combined International Union of Forestry Research Organizations and the International Peat Society (IUFRO-IPS) peatland terminology, specific to the Canadian environment are provided by Stanek (1977). For purposes of the Alberta Peatland Inventory Pilot Project, however, the definitions set by the Wetland Classification System of the National Wetlands Working Group have been adopted to facilitate compatibility with the Canadian Wetland Registry (Tarnocai 1980). These definitions and their sources may be summarized as follows:

Peatlands is a general term used for land covered with a layer of peat, formed by the accumulation of the remains of hydrophytic vegetation. Ford-Robertson (1971) defined peat as an unconsolidated material consisting largely of undecomposed, or only slightly decomposed organic matter accumulated under conditions of excessive moisture.

Wetlands are lands that have the watertable at, near or above the land surface or which are saturated for a long

enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation and various kinds of biological actvity adapted to the wet environment (Tarnocai 1980). This concept of wetlands includes peatlands, mineral soils developed in wet conditions (i.e. Gleysols and the peaty phase of Gleysols), shallow open waters less than 2 m deep, and areas modified by water control structures or by cultivation, but which if allowed to revert, again become saturated for long periods and are associated with wet soils and hydrophytic vegetation. According to this concept, for the Alberta situation, all peatlands can be considered to be wetlands, however not all wetlands are peatlands (Turchenek *et al.* 1984).

Organic soils are soils that are composed mainly of organic materials and include most of the soils referred to as bog soils, muck or peat. According to the Canadian System of Soil Classification (Canada Soil Survey Committee 1978), organic soils are differentiated from mineral soils on the basis of organic carbon content, depth of surface horizons, thickness of underlying unconsolidated mineral material and depth to permafrost.

Of importance here is the criterion that for a soil to be included in the Organic order, the organic surface must extend to a depth of at least 60 cm if the surface layer consists of fibric material, to a depth of at least 40 cm in the event of mesic or humic material, or have more than 10

cm of organic material on rock. Within the Organic order, the primary criterion for classification is the degree of decomposition of the organic material (i.e. Fibric, Mesic or Humic).

The depth of the organic layer has also been used as a basis for differentiating peatlands from non-peatland soils. Jeglum *et al.*(1974) advocated a depth limit of 20 to 30 cm, while Tarnocai (1980) linked the definition of peat to Organic soil by setting 40 cm as the minimum depth. It remains, however, that "peatlands" may include both Organic and Gleysolic soils.

The classification of peatlands as Organic soils, utilizing the Canadian System of Soil Classification, is based entirely on the physical and chemical characteristics of the peat layer, and does not consider associated vegetation cover as a criterion for classification.

2.1.1 MAPPING PEATLANDS IN ALBERTA

Peatlands constitute a major portion of the land base in central and northern Alberta (Figure 1). The Alberta Soil Survey (1967) estimated that there are approximately 10 million hectares of Organic soils in the province, which accounts for nearly 15% of the total provincial land base. More recent estimates (Zoltai and Johnson 1983) suggest an areal extent of 16 million ha.

The discrepancy of 6 million ha suggests that the concepts previously utilized to identify and stratify

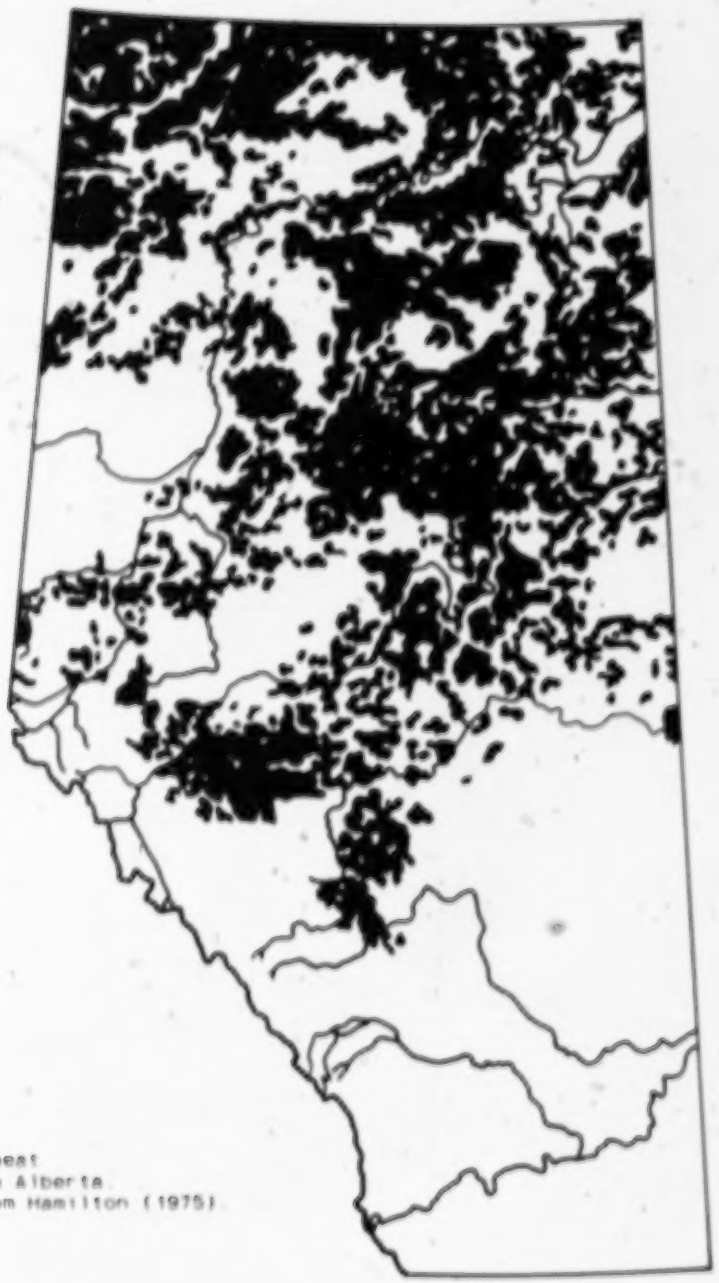


Figure 1. Extent of peat deposits in Alberta. Adapted from Hamilton (1975).

peatlands may not have been restricted to Organic soils. Furthermore, the large extent of peatlands in the province with potential for expansion of agricutural and forestry land bases, industrial mining, and watershed and wildlife management, warrants a need for re-evaluation of the inventory methodology and definitions previously utilized in the mapping of peatlands.

2.1.1.1 Soil Surveys

Historically, peatlands in Alberta were mapped as Organic soils through exploratory and reconnaissance soil surveys, at scales of 1:750,000 and 1:126,720, respectively. Prior to the 1950's, organic soils were not differentiated according to their characteristics. In surveys done during the 1950's to the 1970's, distinctions were made between those soils developed from sedges (Zaglesham soil complex) and those developed from Sphagnum mosses (Kenzie soil complex). A more comprehensive identification of Organic soils was done in the survey of the Sand River Sheet (NTS 73L) by Kocaoglu (1975). This survey utilized map unit concepts that recognized Organic soil associations at the subgroup level in an attempt to describe soil and landform relationships. Further detailed discussion of the mapping of Organic soils in Alberta is presented by Turchenek (1982).

For peatland inventory purposes, previous soil surveys, excepting the Sand River Sheet, generally

contain insufficient information about the stratigraphy, total peat depth, trophic status, degree of decomposition and vegetative cover of associated peatlands (Turchenek *et al*. 1984).

2.1.1.2 Forest Inventory

In Alberta, three types of forest inventory maps are currently available at various levels of detail. The Broad Inventory (Phase I) provides information on species composition, density, height and areal extent, for a minimum stand size of approximately 65 ha at a common scale of 1:100,000. Organic terrain is described as either being "marsh bog" or "muskeg" or "treed muskeg", though it may also be associated with tamarack (*Larix laricina* (Du Roi) K. Koch) or black spruce (*Picea mariana* (Mill.) B.S.P.) forest cover types. The Detailed Inventory (Phase II) utilizes a minimum stand size of 16 ha, a scale of 1:31,680, and similar map units for organic terrain as the Phase I inventory. The Phase III inventory is more detailed, with a minimum stand size of 8 ha at a scale of 1:15,000. Peatlands are represented by three categories, specifically, "treed muskeg", "open muskeg" and "coniferous scrub". As with the two previous inventory levels, Phase III maps do not provide the detailed information required for classification of peatlands, but do contribute information on peatland locations, areas and boundaries. In addition, these maps provide some description of the vegetative cover

associated with peatlands, which is not usually considered in soil surveys.

Forest cover maps therefore, when available, provide information useful for locating peatlands. For large parts of Canada, especially the northern regions, however, there is a lack of reliable information on forest resources, as inventory procedures have not been nationally standardized, and the results, which have been compiled by different agencies, are difficult to correlate (Kalensky *et al*. 1979).

2.1.1.3 Ecological Land Classification

Integration of landforms, soils, drainage, vegetation and climatic information constitutes the mapping units of Ecological Land Classification (ELC) maps. These maps are produced at a scale of 1:100,000 for selected regions of Alberta. For purposes of mapping peatlands, Turchenek *et al*. (1984) suggested that the information provided in ELC maps could be upgraded by adopting the Wetland Classification System (Tarnocai 1980) paired with a physiognomic classification of peatland vegetation. This would facilitate broad categorization of peatlands according to vegetative cover.

2.1.2 THE CANADIAN WETLAND REGISTRY

The Canadian Wetland Registry was initiated in 1978 for purposes of standardizing the collection of site specific

information on wetlands in Canada. The Registry is maintained at the Land Resource Research Institute, Ottawa, Ontario, and serves as a data bank of inventory information available to researchers. The most recent version of the Registry is detailed by Tarnocai (1980).

2.1.2.1 The Wetland Classification System

Developed in conjunction with the Canadian Wetland Registry, the Wetland Classification System incorporates physical and chemical characteristics of peat, as well as the physiognomic characteristics of associated vegetation into a classification scheme for organic and mineral wetlands. This classification system was designed for compatibility with the Ecological Land Classification System, to include information important to a variety of disciplines and to be readily applicable to air photo interpretation with a minimal amount of field checking (Zoltai *et al.* 1975).

The system of classification is carried out at three levels, outlined by Tarnocai (1980) as follows:

1. Class level - the highest level of wetland classification, based on genesis;
2. Form level - classification according to surface morphology, surface pattern, morphology of underlying mineral terrain, hydrology and type of water; and
3. Type level - the lowest level of classification, based on the physiognomy of vegetative cover.

Zoltai and Pollett (1983) discuss a fourth, more detailed level of classification referred to as the "Wetland Variety". This term was developed to facilitate delineation and description of small, homogeneous portions of peatlands for purposes of differentiating vegetational and hydrological characteristics.

In the application of a Wetland Classification System to peatland inventory, modifications may be required to accommodate a particular user's interest or the characteristics of a specific geographical region. This was demonstrated by Jeglum *et al.* (1974), who emphasized vegetative cover rather than surface morphology in the development of a wetland classification for Ontario. Subsequent development of a peatland inventory program for Ontario, initially based on airphoto interpretation and then on analysis of LANDSAT data (Pala and Boissonneau 1981, Pala 1982, Pala 1983) demonstrated that the Wetland Classification System was adaptable to mapping, once vegetation-spectral reflectance characteristics were established. These studies suggest that vegetative cover has significance in the identification of wetlands, and more specifically peatlands.

2.1.3 SUMMARY

In view of the currently available resource inventories, the type of information provided by each is of

limited utility in a peatland inventory for the Boreal region of Alberta. Although these inventories provide information on location and distribution of peatlands, more detailed information is required for peatland inventory.

For detailed inventory purposes, therefore, information on the chemical characteristics (water chemistry, pH, cation exchange capacity) and physical characteristics (fibre content, degree of decomposition, botanical composition and depth) of peat deposits should be incorporated into mapping units representing peatlands. This information is obtained only through site specific sampling. More generalized information (spatial distribution, areal extent and associated vegetative cover) however, may be obtained through reconnaissance level surveys.

The interpretation of aerial photographs has traditionally been a major practice in reconnaissance level mapping of forested and wildland terrain. This procedure involves recognition of landscape units on the basis of the geometry, form and vegetation associations of specific terrain components, and therefore requires well-trained photo-interpreters. When combined with the requirement for large-scale photographs and field-sampling, mapping by photo interpretation becomes an expensive and time consuming procedure for large area resource inventory.

With the advent of the LANDSAT series of satellites in 1972, there has been a growing interest amongst resource managers in the application of satellite data to large area

inventories. LANDSAT MSS digital data provide a multispectral and multidate information base on land cover for large geographical areas. Should it be possible to establish correlations between peatland vegetative cover and associated reflectance properties, LANDSAT MSS digital data could be useful for stratification of vegetative cover at the Wetland Type level of the Wetland Classification System.

2.2 LANDSAT MSS DIGITAL DATA

The development of the LANDSAT series of satellites initiated a major technological advancement in computer-aided analysis of multispectral and multidate data for the inventory and monitoring of large geographical areas. Multispectral data were obtained by the Multispectral Scanner (MSS) payload; multidate data resulted from the orbital periodicity of the satellites.

2.2.1 THE LANDSAT MSS SYSTEM

The MSS of LANDSAT-1,-2,-3 and -4 operated as a line scanning system that provided repetitive coverage of the earth's surface in 185 km wide swaths. Currently, only LANDSAT-5 is fully operational and maintains a similar path of coverage. These systems were designed to record earth-reflected sunlight in 4 spectral bands (Table 1), while the MSS of LANDSAT-3 recorded an additional band of emitted infrared radiation (10.4 - 12.6 μm).

TABLE 1. LANDSAT MSS AND SATELLITE CHARACTERISTICS

MSS Detector[1] System			
Spectral Response[1]	Band 4	0.5 - 0.6 μm	(visible green)
	Band 5	0.6 - 0.7 μm	(visible red)
	Band 6	0.7 - 0.8 μm	(reflected Infrared)
	Band 7	0.8 - 1.1 μm	(reflected Infrared)
	Band 8	10.4 - 12.6 μm	(emitted Infrared)[2]
Detector Configuration:	Bands 4,5,6 and 7, 6 detectors per band Band 8, 2 detectors		
Instantaneous Field of View, linear	~79 m (237 m for Band 8)		
Satellite Parameters	**LANDSAT-1,-2,-3**		**LANDSAT-4,-5**
Altitude:	~913 km		~705 km
Periodicity:	18 days		16 days
Orbital Path:	Sun-synchronous, north to south		
Canadian Based Receiving Station:	Prince Albert, Saskatchewan		

[1]LANDSAT-4 and -5 Band numbers are 1, 2, 3 and 4, respectively.
[2]LANDSAT-3 only.

Adapted from Lillesand and Kiefer (1978) and Freden and Gordon (1983).

Analog signals produced by the LANDSAT MSS detectors are digitized and subsequently relayed to earth-based receiving stations for radiometric calibration and correction (Ahern and Murphy 1978), and formatting to computer-compatible tapes (CCT's). Comprehensive reviews of the physical parameters of the LANDSAT satellites' structure and operation are provided by Lillesand and Kiefer (1979) and Freden and Gordon (1983).

2.2.2 CHARACTERISTICS OF MSS DIGITAL DATA

The MSS digital data are available as high-density (9 track, 800 and 1600 bpi) digital tapes. These CCT's consist of digital values corresponding to the relative intensity of sunlight reflected from the earth's surface, in each spectral band recorded (Table 1).

The size of the resolution cell, derived from the linear field of view (Table 1) is approximately 79 m x 79 m for LANDSAT-1, -2, and -3, and 82 m x 82 m for LANDSAT-4 and -5. These resolution cells approximate a ground area of 0.6 ha, and are referred to as "pixels", the acronym for "picture elements". Each pixel is assigned a radiometric value within the range of 0 (low intensity reflectance) to 255 (high intensity reflectance) for each spectral band recorded.

The potential advantages of LANDSAT imagery for the inventory of peatlands are the sequential coverage, the synoptic view of large inaccessible areas and the

multispectral data that may be analyzed singly or in any combination (Liang and Philipson 1981). The major limitations of the data are the spatial, spectral and temporal resolutions and the lack of information on topography.

2.2.2.1 Spatial Resolution

Spatial resolution refers to the minimum distance between two objects that a sensor can record distinctly. For the LANDSAT MSS system, this is expressed in terms of the instantaneous field of view (IFOV), and is a function of the satellite orbital altitude, detector size and the focal length of the optical system (Simonett 1983).

For the reflected visible and infrared bands sensed by the LANDSAT-1, -2, and -3 MSS (Table 1), the linear field of view is commonly quoted as being 79 m (Simonett 1983), but changes in orbital altitude have caused the size to vary between 76 m and 81 m (Gordon 1980).

The nominal LANDSAT -1, -2 or -3 resolution cell is approximately 59 m x 79 m, due to pixel overlap resulting from the continuous motion of the scanner system. Images derived from line scanning systems have one-dimensional relief displacement, but due to the high orbital altitude and narrow field of view (Table 1), LANDSAT MSS images contain little to no relief displacement in areas of moderate relief (Lillesand and Kiefer 1979).

2.2.2.2 Spectral Resolution

Spectral resolution refers to the width of the specific wavelength intervals or "Bands" recorded by a sensor. The spectral resolutions of the LANDSAT MSS systems are outlined in Table 1.

Generally, information of Band 4 (visible green), although affected by scattering, has been reported useful for differentiation and vigor assessment of vegetation and Band 5 (visible red) for identification of vegetation and geologic and cultural (agriculture, forestry and urban) features. Band 6 and Band 7 (reflected infrared) are often used for vegetation biomass studies and delineation of water bodies and cultural features (Barrett and Curtis 1982, Freden and Gordon 1983).

A common problem related to both the spatial and spectral resolution of the LANDSAT MSS system is the occurrence of "boundary pixels". Depending on the ground location of the pixel, the recorded radiometric value may be that of one cover type, or the average of several different cover types. Consequently a boundary pixel may be assigned a radiometric value that is not representative of any terrain components within the pixel (Thie 1976). Boundary pixels are likely to occur in areas of spatially complex vegetation associations, in transition areas, and when specific components are smaller than the resolution cell. Boundary pixels have

been implicated as serious deterrents to the establishment of representative spectral signatures for implementation of classification procedures in a variety of environments (Driscoll *et al.* 1974, Tarnocai and Kristof 1976, Thie 1976, Pala and Janc 1981, Wickware and Howarth 1981).

2.2.2.3 Temporal Resolution

Temporal resolution is dependent upon the periodicity of the LANDSAT satellites (Table 1). Repetitive coverage of the earth's surface facilitates collection of spectral data for more than one date at a given location, allowing for "multidate" or "multitemporal" analysis (Estes and Simonett 1975, Lillesand and Kiefer 1979). Analysis of multidate data is based largely on the observation that with time, specific ground features undergo changes that influence their spectral response characteristics. These changes may be the result of physiological changes related to seasonal growth of vegetation, environmental influences (flooding or fire) and cultural practices (agriculture or forestry), or temporal variations in climate, atmosphere, and solar altitude. Time-periodic environmental characteristics affect the optimum time for imaging and discrimination of earth surface features, such that diurnal, seasonal and multi-annual effects are often utilized to improve the spectral separability of within-scene features (Estes *et al.*

1983).

Of major concern in multidate analysis is the need for precise registration of the digital data. Ideally, every pixel at the same image coordinates for each data set utilized should represent the same location on the earth's surface, but spatial congruency is never completely achieved in practice (Estes *et al*. 1983). Consequently, interpretation of results of multidate analysis must be done cautiously. According to Wickware and Howarth (1981), the likelihood of error in change detection based on digital classification is more pronounced for isolated pixels than for groups of pixels.

2.2.3 ANALYSIS PROCEDURES

Analysis of LANDSAT MSS digital data may be accomplished through direct visual interpretation of hardcopy imagery, or through computer-aided techniques. Computer-aided analyses may be qualitative, involving image enhancement procedures, or quantitative, involving application of classification procedures. An image enhancement procedure transforms the data into a more expressive, interpretable form, while a classification procedure consists of a series of decisions by which image data are converted into discrete classes (Lillesand and Kiefer 1979). Visual interpretation of imagery allows a "quick-look" appraisal of a region, but for purposes of

quantifying specific ground cover types, classification procedures are most often utilized. For example, in the mapping of Boreal environments with LANDSAT digital data, previous work has emphasized classification (Tarnocai and Kristof 1976, Thie 1976, Wickware 1979, Lee 1980, Barnard *et al.* 1981).

2.2.3.1 Image Enhancement

Visual interpretation of LANDSAT MSS digital data involves the use of a color-monitor as a color additive viewer to display an image. Commonly, three spectral bands of data are illuminated using three colors (red, green and blue) to produce color composites of the scene of interest.

Enhancement techniques are often used to accentuate subtle spectral details to increase contrast between features in a scene prior to visual analysis. According to Lillesand and Kiefer (1979), most enhancement techniques may be characterized as being either "point" or "local" operations as follows:

1. Point operations modify the brightness values of each pixel in an image set independently;
2. Local operations modify the value of each pixel in the context of the brightness values surrounding it.

Point operations commonly applied to LANDSAT data include contrast stretch, linear stretch, histogram-equalized stretch, band ratioing and principal component analysis (Taylor 1974, Lillesand and Kiefer

1979). The main purpose of contrast stretch enhancements is to expand the range of pixel values to enable their display over a larger range of grey values (Lillesand and Kiefer 1979). On the other hand, principal component analysis involves mathematical transformations of spectral data to enhance specific scene features (Taylor 1974). The application of principal component analysis has been reported effective for direct visual interpretation of imagery (Lee *et al.* 1977, Rubec and Wickware 1978); for land cover change detection (Byrne *et al.* 1980); and for wetland terrain classification (Shreier *et al.* 1982).

Local operations are generally employed to either emphasize or de-emphasize abrupt changes in pixel brightness values and alter the textural appearance of an image (Lillesand and Kiefer 1979). These methods include low-pass filtering or smoothing, and high-pass filtering or edge enhancement. Johnson and Howarth (1981) found that linear contrast stretch and band ratioing were more effective than filtering for emphasizing differences between land cover types in a subarctic wetland environment.

Color additive viewing and manual adjustment of tonal brightness and contrast have been found to be useful methods of image enhancement in production of images for visual interpretation of wildland and estuarine environments (Kirby 1974, Oswald 1974,

Singhroy and Bruce 1981, Tomlins and Thomson 1981). In addition, enhancement procedures have also been used to locate training areas for supervised classification (Lee 1980, Tomlins and Thomson 1981).

Image enhancement procedures, overall, tend to be very subjective. The application of any individual or combinations of enhancement procedures may only prove effective for a particular date of imagery or study region. Consequently, methodology is difficult to prescribe.

2.2.3.2 Classification

Classification of LANDSAT MSS digital data, in a very broad sense, involves stratification of the data into statistically separable groups or classes. These classes are derived through formulation of 1-, 2- or multidimensional "spectral signatures", with each dimension corresponding to a spectral band of data. Each spectral signature is defined by a mean radiometric value and a standard deviation for each band of data utilized in definition of the class parameters. Detailed reviews of classification methodology specifically for LANDSAT MSS digital data are provided by Goldberg and Shlien (1976), Goodenough (1976), Letts (1978), Park *et al.* (1979) and Estes *et al.* (1983).

Two methods of spectral signature establishment are commonly utilized: "unsupervised classification" involves computerized determination of spectral class

parameters on the basis of statistical relationships within the data; "supervised classification" involves operator definition of "training areas" for which spectral class parameters are then established.

2.2.3.3 Unsupervised Classification

Unsupervised classification is also referred to as "clustering". The ARIES-II system utilizes a migrating means clustering algorithm detailed by Letts (1978). Spectral classes or "spectral signatures" are established through multidimensional histogram analysis. Each spectral band utilized constitutes a single dimension of the multidimensional histogram.

Subsequent classification entails stratification of scene pixels into the spectral classes established by the clustering algorithm. Case studies utilizing multi-dimensional histogram analysis for clustering of LANDSAT digital data are provided by Goldberg and Shlien (1976), Letts (1978) and Park *et al.* (1979).

The major advantage of unsupervised classification is that spectral stratification of ground cover is possible without *a priori* field surveys. Furthermore, the most common spectral categories in an image are quantified (Schreier *et al.* 1982). Unsupervised classification has been reported useful in situations where little or no field data are available or where an area displays extreme heterogeneity in groundcover and terrain features (Driscoll *et al.* 1974, Fleming *et al.*

1975, Tarnocai and Kristof 1976, Beaubien 1979). Disadvantages of the procedure include the need to identify the resultant spectral classes and to relate them to actual ground cover types. Resultant classes, although statistically separable, may not correspond to physiognomically distinct cover types Spectral overlap between different classes or mixed spectral data due to complexities of the environment can prevent the assignment of a unique descriptive name to each spectral class (Johnson and Howarth 1981).

2.2.3.4 Supervised Classification

Supervised classification involves establishment of spectral classes representative of the cover types to be classified. Training samples or "training areas", consisting of pixels representative of known cover are used to establish the statistical parameters of the spectral signatures to be used in classification.

The major disadvantages of supervised classification procedures are the requirements that selected training areas must have spectral characteristics typical of the ground cover types of interest, that exact line and pixel coordinates of training areas be determined, and that the cover types are spectrally separable (Goldberg and Shlien 1976). Supervised classification procedures are most useful when cover types are consistent in density and species composition and are spectrally unique relative to other

cover types over large geographic areas (Fleming *et al.* 1975). The major advantage of the procedure is that spectrally separable ground cover types may be selected for and quantified through classification.

2.2.3.5 Signature Extension

Signature extension involves utilization of spectral signatures developed for cover types in relatively small study segments for the classification of large geographical regions. The major objectives of this procedure are to increase the spatial-temporal range over which spectral signatures may be utilized without significant loss of recognition accuracy (Minter 1978).

Signature extension has been commonly applied to large area inventories of agricultural crops such as wheat (Kauth and Richardson 1978, Minter 1978, Thomas *et al.* 1978), potatoes (Ryerson *et al.* 1981) and canola (Ryerson *et al.* 1982). In contrast, there is a lack of current literature concerning the utilization of signature extension in the inventory of Boreal wildlands.

2.2.4 SUMMARY

In the utilization of LANDSAT MSS digital data, consideration should be given to the potential limitations of the data imposed by the spatial, spectral and temporal resolutions, as well as to limitations of the analysis

procedures. The potential spectral separability of the cover types of interest should also be considered, especially in terms of complexity and variability of vegetation associations and the topographic positions occupied.

Tradeoffs between the spatial, spectral and temporal resolutions are likely to occur in any application of MSS data (Simonett 1983). Recognition of the relationships between these variables and the characteristics of the study area may dictate the choice of imagery and analysis procedures for a particular application.

2.3 LANDSAT MSS DIGITAL DATA FOR PEATLAND INVENTORY

Application of LANDSAT MSS digital data specifically to the mapping of peatlands within Boreal environments has been undertaken in Canada by Pala and Boissoneau (1982), Pala (1982), Pala (1983) and Dixon and Stewart (1984), in Scotland by Stove (1983) and in Sweden by Boresjö (1984).

For the Boreal regions of Canada, however, there exists relatively little information on the specific application of LANDSAT MSS data to peatland inventory as compared to applications for regionalized mapping of land cover types. In the latter, a mapping unit designated as "wetlands", inclusive of a variety of peatlands, is often used with little further distinctions made (Rubec and Thie 1978, Lee 1980, Barnard *et al.* 1981). In contrast, in studies of very localized environments (Pala and Boissoneau 1982, Schreier *et al.* 1982), peatlands have been categorized with

considerable detail.

2.3.1 MAPPING WITH LANDSAT DATA

In attempting to map cover types using LANDSAT MSS digital data as an information base, consideration should be made of the maximum map scale and the specificity of map units possible. Map scale is largely determined by the spatial resolution of the MSS sensor; potential map units are determined by the spectral separability of the cover types of interest.

2.3.1.1 Map Scale

Vogel (1977), cited by Shreier *et al.* (1982), reviewed the capabilities of LANDSAT imagery as a source of terrain data for cartographic and military purposes and concluded that the ground resolution was inadequate for classifying most basic terrain elements. However, he noted that at a scale of 1:100,000 to 1:1,000,000, LANDSAT data were compatible with current map accuracies of the same scales.

According to Forbes *et al.* (1983), when given the number of pixels required for the minimum legible delineation (MLD) on a map based on LANDSAT data, the maximum acceptable map scale may be computed by the formula:

$$\text{Maximum Scale} = 1:\sqrt{(\text{pixel area} \times (\text{pixels/MLD}) \times 25{,}000)}$$

For example, given a 79 m x 79 m pixel size (as for LANDSAT-1, -2 or -3 MSS digital data) and using at least 65 pixels (~40 ha) per MLD, the maximum acceptable scale would be approximately 1:100,000. Production of maps at scales larger than the calculated maximum would be attempting to represent finer ground detail than the resolution of the imagery (Forbes *et al.* 1983).

A mapping scale of 1:100,000 or smaller, may be viewed as a limitation in some applications. The work of Tarnocai and Kristof (1976), Thie (1976), Cihlar *et al.* (1978), Wickware (1978) and Dixon *et al.* (1983), however, has indicated that the mapping of Boreal wetlands using LANDSAT provides an efficient and cost-effective method of inventory. Furthermore, the efforts of Kirby and van Eck (1977), Beaubien (1979), Kalensky *et al.* (1979), Rohde *et al.* (1979), Pala and Jano (1981) and Häme (1984) have demonstrated the utility of LANDSAT data in multistage inventories. In these studies, the general consensus was that the preliminary stratification of land cover based on classification results could expedite location of broad cover classes and selection of field sampling units for subsequent detailed inventories.

2.3.1.2 Map Units

Computer-aided classification of LANDSAT MSS digital data for the mapping of forest and wetland cover types has been applied in a variety of Canadian

environments (Table 2). Most often, the mapping units utilized in these studies were of necessity broad cover classes to accomodate the physiographic complexity and variability of vegetation associations within the study areas.

According to Kalensky *et al.* (1979), the number and types of cover classes and accuracy of a classification depends on the type of terrain, date and quality of imagery, and the method of analysis used. Limitations imposed by the rather coarse spatial and spectral resolution of the LANDSAT MSS data also restrict the specificity of classes (Pala and Jano 1981).

2.3.2 METHODS OF ANALYSIS

The early applications of LANDSAT MSS data for mapping forested terrain within Canadian environments involved visual interpretation of hardcopy imagery (Aldred 1974, Kirby 1974, Oswald 1974, Oswald 1975). Easily recognized features included water bodies, watershed and drainage systems, mountainous topography, landform patterns, grasslands, forested lands, snowfields and major transportation and seismic routes (Oswald 1975). Major limitations to the recognition of forest cover types involved the inability to distinguish cover types of spectrally similar responses and mixed species composition. Multidate imagery and color additive viewing techniques improved interpretations (Kirby 1974).

TABLE 2 CONFUSION OF PEATLAND COVER TYPES IN LANDSAT MSS CLASSIFICATIONS OF CANADIAN ENVIRONMENTS

Confusion Classes	Reasoning	Study Area	Data[1]	Method[2]	Reference
Peatlands with transition areas marginal wetlands lakeshores, shallow water	Variable vegetation density Boundary pixels	Richards Island, N W T	NS[3]	UC	Tarnocai and Kristof (1976)
Sedge bogs with poplar forest	NS	Boreal forests Alberta	S,M	SC	Kirby and van Eck (1977)
Peat bogs with deforested areas regeneration areas fire scars	Diversity of vegetation	Anticosti Island Laurentian Plateau Quebec	S	UC	Beaubien (1979)
Fens with mixedwood forests	Boundary pixels Data misregistration Training area selection	Peace-Athabasca Delta, Alberta	M	SC	Wickware (1979)
Peatlands with coniferous forests	Boundary pixels Variability in tree cover	Northern Ontario	M	SC	Pala and Jano (1981)
Sedge fens with bogs	Similarity in vegetation Variability in tree cover	Churchill, Manitoba	M	SC	Schreier *et al.* (1982)
Bogs with coniferous forest mixedwood forests	Variability in bog spectral response	Cross Lake, Manitoba	S	UC	Dixon *et al.* (1984)

[1] S=Single date, M=Multidate.
[2] UC=Unsupervised classification, SC=Supervised classification
[3] NS=Not stated.

The overall consensus of these studies was that stratification of broad land cover types could be accomplished through visual interpretation, but that the level of stratification was dependent upon the date of imagery, the areal extent and spectral responses of groundcover types, and the availability of *a priori* field information. Similar conclusions regarding the separability of cover types were drawn in the early attempts to utilize computerized classification procedures (Kalensky and Sayn-Wittgenstein 1974, Tarnocai and Kristof 1976, Kirby and van Eck 1977, Lee *et al.* 1977).

The literature contains conflicting reports regarding the utility of unsupervised and supervised classification procedures for mapping wildlands. Tarnocai and Kristof (1976), Beaubien (1979) and Schreier *et al.* (1982) have reported successful stratification of Boreal wetland and forest cover types through application of unsupervised procedures. More recently, the work of Dixon *et al.* (1984) has suggested potential utility of unsupervised classification for mapping wetland (bog, marsh or water) habitats.

In studies that compared both unsupervised and supervised classification, the latter was most often favored for identification of specific cover types (Thie 1976, Lee *et al.* 1977, Cihlar *et al.* 1978, Kalensky *et al.* 1979, Wickware 1979). In these studies, major difficulties encountered with unsupervised classification involved the

interpretation of resultant spectral classes, which often represented more than one cover type. Supervised classification has also been advocated by Pala and Jano (1981), Tomlins and Thomson (1981) and Dixon and Stewart (1984) for mapping wetlands and associated peatlands.

In contrast, Pitblado and Amiro (1982) reported that neither supervised nor unsupervised classification were particulary useful for vegetation mapping, even when applied to multidate data. Their findings were attributed to the complexity and variability of vegetation associations within their study region.

The inability to decipher unsupervised classes or to locate representative training areas for supervised classification procedures in forested regions of the United States led to the development of a "modified clustering" technique by Fleming *et al.* (1975). This involved clustering of selected training areas to identify inherent spectral variability, subsequently used as a basis for redefinition of training areas. Further development of hybrid classification techniques by Hoffer and Fleming (1978) and Hoffer and Swain (1980) demonstrated that classification results could be improved when the spectral variability of cover types was recognized prior to development of spectral signatures. The use of similar hybrid techniques, however, is not reported within Canadian literature.

The success of digital classification procedures appears to be largely a function of the spectral

separability of the groundcover types, and according to Pitblado and Amiro (1982), the scale of the investigation, stand purity and the availability of reliable ground survey data.

2.3.3 SPECTRAL SEPARABILITY OF COVER TYPES

The successful application of image enhancement and classification procedures is highly dependent upon the spectral separability of the ground cover types of interest.

Species composition, age and density of vegetation cover, and percent and aspect of slope influence reflectance characteristics of the associated terrain (Beaubien 1979). Stress conditions, geometric configuration of the vegetation, and environmental variables such as insect and disease infestations, soil moisture and wind also cause variations in spectral responses (Hoffer 1978), as well as atmospheric conditions (Colwell 1974), and background reflectance (Dana 1982).

Within wildland regions, heterogeniety of cover types also manifests variability in spectral responses and creates difficulty in the establishment of spectrally homogeneous classes. This complicates both supervised and unsupervised classification procedures. In both cases, the spectral classes derived from statistical relationships within the data may be representative of more than one cover type, either as the result of a large standard deviation associated with a spectral signature, or to the spectral

similarity of various ground cover types. This significantly restricts the specificity of spectral classes and resultant map units.

The use of multidate data may facilitate refinement of spectral signatures, but contradictory reports exist regarding the utility of multidate data in classifications (Table 2). Beaubien (1979) advised against multidate analysis for large study areas because of an associated risk in introduction of other temporal variables. For change detection purposes, however, multidate analysis has been proven useful by Kirby (1974), Lee *et al.* (1977), Wickware (1979), Schreier *et al.* (1982). In addition, Kirby and van Eck (1977), advocated overlaying single date classification results for production of multidate composite maps.

The success of multidate analysis is highly dependent upon the spectral separability of cover types, phenologically related spectral characteristics and the dates of imagery utilized. Consequently, multidate analysis may be more useful in the detection of significant changes in ground cover as a consequence of flooding or fire, than in identification of pigmentation changes or other responses to environmentally induced stress conditions.

Spectral separability has been and continues to be a major problem in regions characterized by complex vegetation associations (Pitblado and Amiro 1982, Häme 1984). The problem of spectral separability is compounded when similar cover types produce different spectral responses (Kalensky

and Wilson 1975), when different types of groundcover produce similar responses (Hame 1984), and when heterogeneity of cover types results in a large proportion of transition areas and boundary pixels (Tarnocai and Kristof 1976, Wickware and Howarth 1981, Pala and Jano 1981, Boresjö 1984).

Spectral confusion of peatland and non-peatland cover types has been commonly reported in the literature (Table 2). Heterogeneity of peatland vegetation cover, similarity of spectral responses of peatland and non-peatland cover types, and the type of classification procedure utilized contribute to potential spectral confusion between peatlands and non-peatlands, as well as between various peatland types. Furthermore, difficulty has been reported with the spectral separation of coniferous and deciduous stands (Fleming *et al.* 1975), mixed and hardwood stands (Beaubien 1979) and of various conifer types (Driscoll *et al.* 1974, Beaubien 1979, Pala and Jano 1981).

The separation of specific peatland and wetland vegetation associations has also proven difficult (Wickware and Howarth 1981, Schreier *et al.* 1982). In these studies, the majority of the spectral confusion was attributed to the heterogeneity and complexity of cover types and to the methods of analysis used.

The literature indicates that stratification of peatland types is better accomplished when localized inventories are done in regions dominated by peatlands, such

as in the work of Pala and Jano (1981) and Pala (1982) in the Hudson Bay Lowlands. Studies in very localized areas exclusive of uplands, such as those of Wickware (1979) in the Peace-Athabasca Delta, and Tomlins and Thomson (1981) in the Fraser River Estuary, have also reported favorable results for classification of specific wetland community types. In contrast, regionalized inventories in areas characterized by both uplands and peatlands result in a greater frequency of confusion between cover types (Tarnocai and Kristoff 1976, Rubec and Wickware 1978, Barnard *et al.* 1981, Boresjo 1984, Hame 1984). It follows then, that areas of great complexity in vegetation associations are more likely to produce problems of confusion and multiple classifications than are those of lesser complexity.

2.3.4 ASSESSMENT OF CLASSIFICATION ACCURACY

Assessment of classification accuracy is fundamental to the decision to utilize LANDSAT MSS data and specific analysis procedures for inventory purposes. Within current literature, however, there is a lack of consistency in the methodology utilized for accuracy assessment. Furthermore, the lack of standardized methods for expression of accuracy has led to development of methods for description and quantification of classification errors on an *ad hoc* basis (Mead and Szajgin 1982).

Two frequently used methods of accuracy assessment procedures, "site specific" and "non-site specific", are

described by Mead and Szajgin (1982) as follows:

1. Site specific accuracy assessment involves registration of two spatially defined data sets to determine agreement. Comparisons are made on a point by point, grid cell or polygon basis and results are expressed in confusion matrices.
2. Non-site specific accuracy is expressed as the similarity between the total areal extent of each cover type determined by a classification effort and the total areal extent determined by reference data (field measurements or aerial photo interpretations). Total acreages are compared without regard to location.

The type of reference data utilized may significantly influence resultant classification accuracies. Aerial photographs have commonly been used as reference data (Barnard *et al.* 1981, Wickware and Howarth 1981, Schreier *et al.* 1982) and occasionally as the base source of data for maps used as reference data (Rubec and Thie 1978, Tomlins and Thomson 1981). Field surveys have also served as a source of reference data (Tarnocai and Kristof 1976, Cihlar *et al.* 1978, Häme 1984), as well as combined aerial photograph interpretations and field surveys (Kirby and van Eck 1977, Beaubien 1979, Boresjö 1984). In some studies, map accuracy has not been established due to lack of uniformity in cover classes (Lee 1980), lack of reliable ground survey information (Beaubien 1979) or the simplistic nature of the study area (Pala and Jano 1981).

Comparison of classification results with aerial photos or with maps based on aerial photo interpretations does not, in actuality, constitute an assessment of classification accuracy. Rather, the procedure is an assessment of the compatibilty of computerized classification results with another type of interpretation. A truer representation of classification accuracy is obtained only when actual field surveys are utilized.

The results of accuracy assesments based on reference data have been commonly expressed non-parametrically as "confusion matrices" or "error matrices". These matrices are portrayed as a square array of numbers set out in rows and columns which express the number of pixels assigned as a particular cover type relative to the actual cover types as verified by reference data (Congalton *et al.* 1983). Rows of the matrix usually represent the computer-defined categories, and columns represent the reference data.

The expression of accuracy as a confusion matrix is effective in valuation of errors of inclusion or "commission errors" and errors of exclusion or "omission errors" present in a classification (Congalton *et al.* 1983). In addition, the matrix format facilitates determination of classification performance for individual categories as well as for the overall classification (Hoffer and Fleming 1978).

When a confusion matrix is utilized, an "overall" performance accuracy is often the only accuracy reported (Hoffer and Fleming 1978, Tomlins and Thomson 1981, Dixon *et*

al. 1983). As the values on the major diagonal of the matrix represent correctly classified pixels, summation of these values and subsequent division by the total number of pixels classified produces a number that is often interpreted as representing overall performance accuracy (Congalton *et al.* 1983).

According to Kalensky *et al.* (1979), confusion matrices do not represent classification accuracy, but rather, they express the similarity between training areas (used for generation of classification statistics) and control areas (used for accuracy evaluations). Furthermore, use of training set data for accuracy assessment results in biased and usually inflated estimates of accuracy; therefore a final evaluation of classification results should utilize an independent sample exclusive of training set data (Mead and Szajgin 1982).

Misrepresentation of classification accuracy also occurs when the discussion of omission and comission errors is avoided. As some cover types (water bodies, rivers and agricultural lands) are easily identified relative to complex forest cover types, it is possible to obtain impressively high overall classification accuracies in wildland situations. In such cases, reported accuracies may be interpreted as favorable, although accompanied by large comission errors. This is demonstrated in the work of Dixon *et al.* (1983) and Dixon and Stewart (1984).

Parametric methods of estimating the reliability of classifications involve calculation of the percentages of cover classes correctly classified and associated confidence intervals (Todd *et al.* 1980). Thomas and Allcock (1984) stress that a classification result is related to reference data by a confidence level, and provide methodology for assignment of appropriate confidence levels to classification results based on the number of samples used in field verification. Assignment of confidence intervals to classification results has been recently demonstrated by Dixon *et al.* (1983) and Boresjö (1984). However, this procedure necessitates the use of a large number of field samples as verification data, and is usually not practical (Kalensky *et al.* 1979, Todd *et al.* 1980, Thomas and Allcock 1984).

2.3.5 SUMMARY

The utility of LANDSAT MSS digital data in mapping peatlands is highly dependent upon the original inventory objectives and the characteristics of the study region. The map scale and detail of map units attainable is determined by the spectral separability of cover types, the intensity of the inventory and the availability of field verification data. Heterogeneity of the study area, especially in terms of the spatial distribution of landforms and the variability in associated vegetation cover influences the spectral separability of the cover types and subsequent specificity

of map units.

In wildlands, the stratification of broad cover classes can be achieved with either image enhancement or digital classification procedures, but detailed maps require ancillary field data for verification and accuracy assessments. Spectral confusion of cover types tends to be the most limiting factor in mapping of wildlands, but can be resolved in some cases through multidate analysis and modified classification procedures.

3. STUDY AREA

The study area for the Peatland Inventory Pilot Project is located within the Athabasca-Calling Lake region of Alberta (Figure 2). This area lies within the Mid-Boreal Wetland Region (Wetlands Working Group 1981), and is characterized by a variety of forest and peatland vegetation associations.

For purposes of LANDSAT MSS digital data analysis, two 625 km² study segments were selected (Figure 2). Due to the need for geometric correction of the MSS digital data, Universal Transverse Mercator (UTM) coordinates served as the bounds for the two study segments, rather than Dominion Land Survey Boundaries.

The two study segments were characterized by a variety of topographic and vegetative associations, a potential indication of the spectral complexity of the area. This condition appears to be typical of the Boreal Forest Region, which has been previously described as highly heterogenous, comprised of forest cover types affected by extensive past fire histories, variations in soil drainage, topography and adverse climatic conditions (Kirby and van Eck 1977, Rubec and Wickware 1978, Kalensky *et al.* 1979). Accessibility was made possible within the study areas by county roads, a network of natural gas well site access roads and cutlines, and by helicopter.

Figure 2. Sketch map of Alberta showing locations of Study Areas 1 and 2.

3.1 SURFICIAL GEOLOGY AND PHYSIOGRAPHY

This region was overridden by the Laurentide ice sheet during the Wisconsin glaciation. The area is mantled by glacial drift ranging in thickness from a few meters to over 46 m, except for the bedrock outcroppings along the valley walls of the Athabasca and North Saskatchewan Rivers (St-Onge 1972).

The region is part of the Alberta Plains, and is mainly an undulating plain with several isolated areas of rolling to hilly topography (Kjearsgaard 1972). Regions of hummocky moraine are characterized by knob and kettle topography, hills up to 30 m high, many small lakes and marshy depressions (St-Onge 1972). In addition, glacial lake basins extend into the region from adjoining areas, with glaciofluvial gravels and sands having been reworked into dunes and stabilized by vegetation (St-Onge 1972). The elevation of this region varies between 523 m to 708 m above sea level (Kjearsgaard 1972).

Throughout this rolling morainal plain, a series of waterbodies and surface drainage networks are interspersed with pure and mixed stands of upland forests and a diversity of peatlands.

3.2 DRAINAGE

Regional drainage occurs by way of the Athabasca River to the Arctic, through tributaries of the Calling, Pembina, Tawatinaw, La Biche and Pine Creek Rivers.

Numerous lakes, ranging in size from a few to several thousand hectares occur in the region. Peat deposits have developed in poorly drained areas of level to depressional topography, along lakeshores and in localized drainage channels.

3.3 CLIMATE

The climate of the region is Continental, characterized by cold winters, warm summers and low precipitation (Kjearsgaard 1972, Wetlands Working Group 1981).

Mean monthly temperatures range from -16°C for January, the coldest month, to 16°C for July, the warmest month (Kjearsgaard 1972). The frost free period ranges from 65 days to 112 days, with conditions becoming more severe towards northern areas (Wynnyk *et al.* 1956, Kjearsgaard 1972). Precipitation occurs mainly during the summer months, ranging from 35 cm to 46 cm (Wynnyk *et al.* 1956).

3.4 SOILS

This region has been previously surveyed by soil surveys at the exploratory level (Wynnyk *et al.* 1956) and at the reconnaissance level (Kjearsgaard 1972).

Soils of the Tawatinaw map sheet (83-I), that occur in well to imperfectly drained positions have been identified at the series level (Kjearsgaard 1972). According to this survey, their relative proportions according to Order, are Luvisols (40%), Chernozems (12%), Brunisols (10%) and

Gleysols (10%).

Organic soils, although occupying approximately 25% of this region were identified only at the Great Group Level. This was attributed to their inaccessibility due to waterlogged and frozen conditions. Of the organic soils identified, Fibrisols were of a much greater occurrence than Mesisols (Kjearsgaard 1972).

3.5 VEGETATION

The study segments lie within the area designated as the Mixedwood Section of the Boreal Forest Region (Moss 1955, Rowe 1959). The history of the vegetation in this region, as determined by Lichti-Fedorovich (1970), indicated the presence of trees 11,400 ^{14}C years ago. At the turn of the century, forest fires ravaged vast spruce forests resulting in large stands of aspen throughout the region (Kjearsgaard 1972).

Undisturbed vegetation cover of upland regions has been referred to as the "Poplar Association" (Moss 1955) and is characterized by pure and mixed stands of trembling aspen (*Populus tremuloides* Michx.), with lesser amounts of white spruce (*Picea glauca* (Moench) Voss), paper birch (*Betula papyrifera* Marsh.) and balsam poplar (*Populus balsamifera* L.) in poorer drained areas. Shrub cover includes a variety of willows (*Salix* L.), dogwood (*Cornus stolonifera* Michx. and *C. canadensis* L.) and mountain alder (*Alnus tenuifolia* Nutt.). Grass cover is dominated by marsh reedgrass

(*Calamagrostis canadensis* (Michx.) Beauv.) and slender wheatgrass (*Agropyron trachycaulum* (Link) Malte).

Sandier soils support stands of jack pine (*Pinus banksiana* Lamb.) and alder (*Alnus crispa* (Ait.) Pursh).

In wet locations where organic deposits are found, considerable variations occur in density and type of groundcover, a reflection of the wide ranges in wetness (Kjearsgaard 1972). Black spruce (*Picea mariana* (Mill.) B.S.P.) is the dominant tree species, with tamarack (*Larix laricina* (Du Roi) K. Koch) also being very common. Shrub associations include dwarf birch (*Betula glandulosa* Michx.), bog birch (*Betula pumila* L. var. *glandulifera* Regel) and willows (*Salix* L.). Ericaceous shrub associations include Labrador tea (*Ledum groenlandicum* Oeder), leatherleaf (*Chamaedaphne calyculata* (L.) Moench) and bog cranberry (*Vaccinium oxycoccos* L.) and frequently comprise the understory of black spruce stands. Brown mosses (*Aulacomnium* spp, *Drepanocladus* spp and *Tomenthypnum* spp), *Sphagnum* spp, Feather mosses (*Hylocomium* spp, *Pleurozium* spp and *Ptilium* spp) and lichens (*Cladina* spp) are characteristic of peatlands in this region. Sedges (*Carex aquatilis* Wahl., *C. disperna* and *C. lasiocarpa*) are associated with lakes and drainage channels. Common emergent species include *Juncus* spp, *Scirpus* spp and *Typha* spp.

3.6 PEATLANDS

The three major peatland classes indigenous to the study area are fens, bogs and swamps (Turchenek *et al.* 1984). Fens are the most common, and occur in depressional areas, along lake shores and in intermittent or linked drainage channels. Vegetation composition ranges from 0 to 80% tree cover (black spruce and tamarack) and 0 to 90% shrub cover. Bogs occur in topographically confined depressions and range in vegetation composition from 1 to 75% tree cover (black spruce and tamarack) and 0 to 90% shrub cover. Swamps occur on the perimeter of large, deep peatlands, or along banks of continuously flowing or semi-permanent streams, and may range in tree and shrub cover from 0 to 60%.

The range in tree and shrub cover associated with each major peatland type in this area required utilization of a classification system whereby tree cover would be considered. This was necessary to ensure compatibility with LANDSAT data, which is basically terrain-vegetation reflectance data. Peatland types were classified according to the physiognomic classification system of Zoltai and Johnson (1983), with a further modification made to consider the amount of tree cover.

According to field surveys conducted during the summer of 1983, the most commonly occurring peatland types in the study areas were:

1. Treed Fen;
2. Shrubby Fen;
3. Lightly Treed Fen;
4. Forested Bog;
5. Wooded Bog; and
6. Sedge Fen.

The vegetation associations of each of these major peatland types are summarized in Table 3. Plates 1, 2 and 3 provide an overview of the physiognomic complexity and spatial variability of peatland and forest cover types within the study areas.

TABLE 3. SURFACE VEGETATION COVER OF PEATLAND TYPES

PEATLAND TYPE	SURFACE VEGETATION COVER		
	% Tree Cover	Overstory	Understory
Treed Fen	30 - 60	*Larix laricina* and/or *Picea mariana*	*Betula pumila* *Salix* spp Ericaceous shrubs Brown mosses *Sphagnum* spp
Lightly Treed Fen	10 - 30	*Larix laricina* and/or *Picea mariana*	similar to Treed Fen
Shrubby Fen	<10	*Salix* spp and/or *Betula pumila*	Ericaceous shrubs Brown mosses *Sphagnum* spp
Sedge Fen	0	*Carex* spp	Brown mosses
Forested Bog	30 - 60	*Picea mariana*	Ericaceous shrubs *Salix* spp *Sphagnum* spp Feather mosses
Wooded Bog	10 - 30	*Picea mariana*	Ericaceous shrubs *Sphagnum* spp *Cladina* spp

Adapted from Turchenek *et al.* 1984.

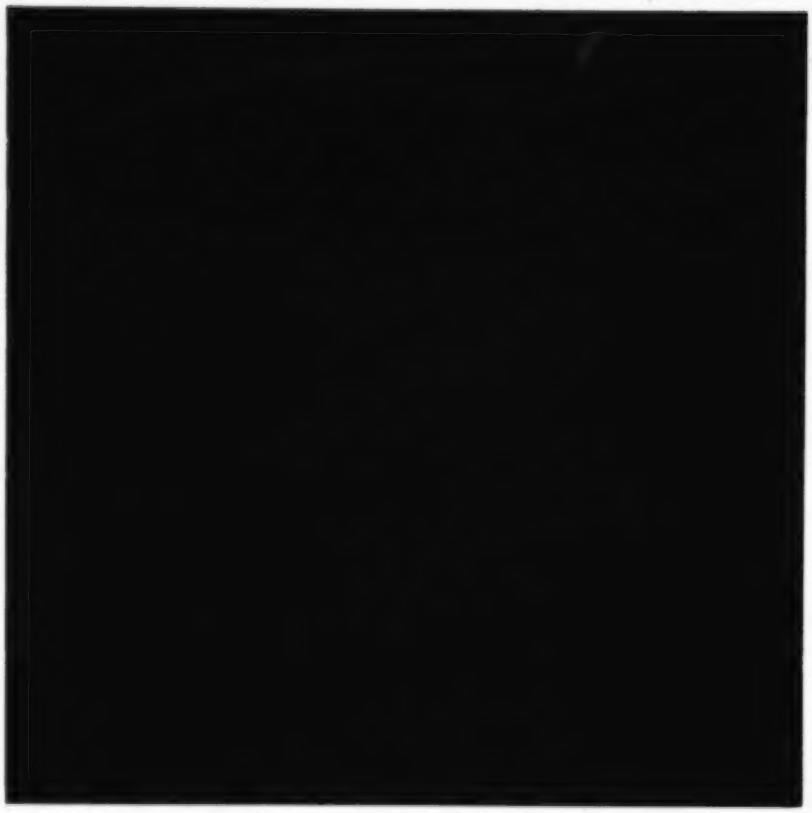


Plate 1. Fen complex within Study Area 1. Foreground depicts Treed Fen grading into Lightly Treed Fen. Central portion consists of Shrubby Fen and Sedge Fen

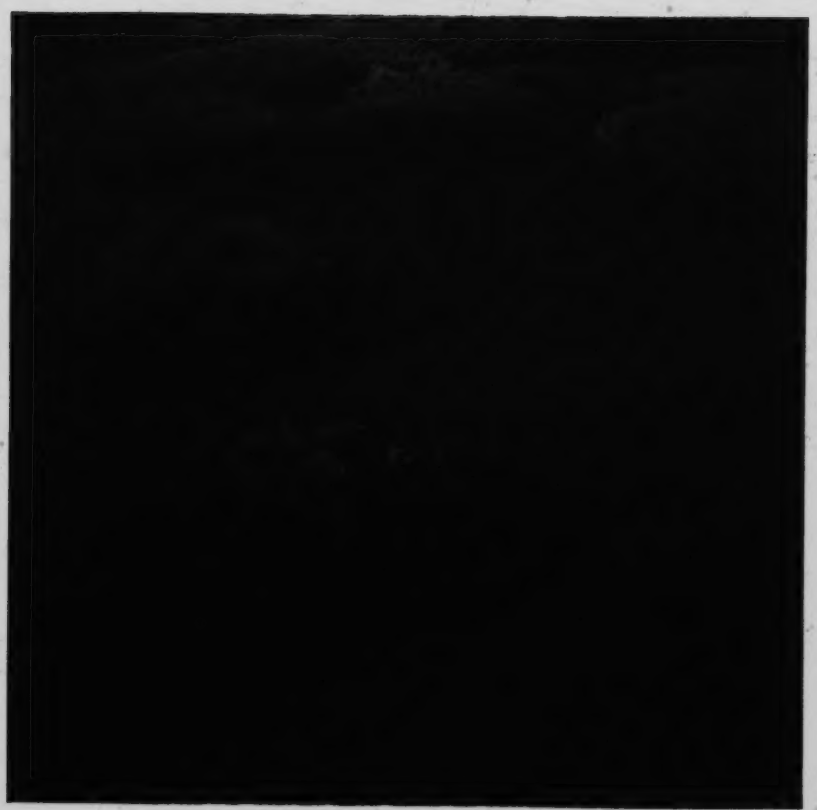


Plate 2. Bog complex within Study Area 1. Foreground depicts Forested Bog and Wooded Bog. Background depicts Aspen uplands.

Plate 3. Aerial overview of a portion of Study Area 1, depicting spatial variability of vegetation cover.

4. MATERIALS AND METHODS

4.1 SATELLITE DATA ACQUIRED

System corrected LANDSAT-2 computer compatable tapes for 12 May 1981 (image #22302-17525) and 15 September 1981 (#22428-17505) were acquired from the Prince Albert Satellite Station. This imagery provided nearly cloud-free coverage of the Athabasca-Calling Lake region.

Multitemporal analysis has been reported useful in detection of phenological and spectral changes associated with seasonal growth of vegetation (Kirby 1974, Wickware 1979 and Schreier *et al.* 1982). A large proportion of the vegetation cover in the study area consists of deciduous species (*Populus* and *Salix*) and sedges (*Carex*) that undergo phenological and spectral changes associated with seasonal growth patterns. Multitemporal analysis therefore, should facilitate spectral separation of these cover types.

4.2 SUPPLEMENTARY DATA ACQUIRED

A series of black and white infrared vertical air photographs (1:30,000 and 1:50,000 scale), soil survey (1:126,720 scale) and NTS maps (1:50,000 scale) facilitated the location of geographical features, upland forests and peatlands. During the summer of 1983, field surveys and helicopter reconnaissance contributed site specific soil and ground cover descriptions for both study areas.

4.3 DIGITAL IMAGE ANALYSIS

Image processing and analysis were performed using a DIPIX System Ltd. ARIES-II image analysis system housed in the Department of Soil Science, University of Alberta.

4.3.1 PRECLASSIFICATION PROCESSING

One quarter of each Landsat scene containing the chosen study areas was geometrically corrected (Bernstein and Ferneyhough 1975, Shlien 1979) and registered to the UTM coordinate system to enable delineation of study areas and registration of multidate data.

The May data was geometrically corrected by manual selection of twelve ground control points from 1:50,000 NTS maps and 1:30,000 and 1:50,000 aerial photographs. The ground control points were distributed throughout the chosen study areas, with consideration given to their distribution along the edges and in the center of each image (Orti 1981). Coefficients of a first-order affine transformation (Moik 1980) were applied to each spectral band of data, followed by cubic convolution resampling (Bernstein and Ferneyhough 1975, Moik 1980) of the original 79 m x 59 m pixels to 50 m x 50 m pixels. For the May data, pixel residual error was maintained below one half pixel, at 24.5 m and 22.2 m for the Easting and Northing, respectively (Appendix 1.1). The September data was corrected by image-to-image registration with the corrected May data. Pixel residual errors were 24.5 m for the Easting and 24.0 m for the Northing (Appendix

1.2).

4.3.2 IMAGE ENHANCEMENT

Color additive viewing techniques were utilized in the production of color composite images on a color monitor for preliminary visual interpretation of the study areas.

A "piece-wise" linear stretch (Lillesand and Kiefer 1979, and ARIES II Manual 1982) was applied to Bands 4, 5 and 7 of the May and September data to enable the display of each band of data over a fuller range of grey-scale values. The data were manipulated using piece-wise stretch procedures until a desired level of contrast was achieved for the various ground cover types within the study areas. Each study area was viewed sequentially as a single-band, grey-scale image on the color monitor, as origninal radiometric values were assigned new values on a piece-wise basis (Appendix 2.1 and 2.2). This procedure necessitated creation of new spectral data files to be used only in color additive viewing.

Single date and multidate color enhancements were produced first as color-composites on the color monitor and then as hardcopy imagery. Recording of the color composites consisting of the piece-wise stretched data was accomplished using the facilities of the Alberta Remote Sensing Center.

4.3.2.1 Single Date Data

Simulation of the color renditions associated with color infrared photographs was achieved through

sequential illumination of Bands 7, 5 and 4 through red, green and blue colored light, for both May and September data.

The enhancement proposed by Singhroy and Bruce (1981), whereby Bands 5, 6 and 7 of October imagery were projected through red, green and blue respectively, was applied to both the September and May data. The technique of Tomlins and Thomson (1981), in which Bands 4, 5, and 6 were projected as blue, green and red, respectively, was also investigated. In addition, various other combinations of data illuminations were explored.

4.3.2.2 Multidate Data

Production of colored multidate composite images involved visual assessment of several colored light illuminations of various combinations of multidate data.

4.3.3 UNSUPERVISED CLASSIFICATION

In application of the clustering algorithm available on the ARIES II system, the operator is given the option of specifying parameters for the feature limits and width of histogram partitions (bin sizes) to be used in the computations. This provides for some operator control over the derivation of spectral classes, referred to as "maxima classes".

4.3.3.1 Histogram Analysis

Minimum and maximum radiance values or "feature limits" for each spectral band of both dates of data were determined through the analysis of individual histograms of radiometric values contained in each band of data. These feature limits were subsequently utilized in the clustering algorithm.

Two distinct sets of feature limits were obtained. Firstly, individual band histograms of the entire study area were used to determine "entire area" feature limits. Secondly, peatland areas were located using existing soil maps (Kjearsgaard 1972) and visual analysis of aerial photographs and color enhanced multidate (May Bands 7 and 4, September Band 7) imagery. Several peatlands were outlined and subsequently formatted to irregular shaped area feature files.

Histograms of these "peatland area" feature files were obtained for all bands of both image dates, and "peatland area" feature limits were then determined.

4.3.3.2 Signature Generation and Classification

Based upon the variation in feature limits of the entire area and peatland areas, it was hypothesized that utilizing the feature limits of the peatlands would bias signature generation towards peatland cover types through application of the clustering algorithm.

To test this hypothesis, three case studies were designed to compare clustering of single date (May and

September Bands 4, 5, 6 and 7) and multidate (May and September Bands 5 and 7) data, for Study Area 1 as follows:

4.3.3.3 Case Studies

Case 1 involved application of the clustering algorithm to the entire study area, utilizing the feature limits designated by the "entire area" histograms (Table 4). Signatures generated were based on the parameters of resultant maxima classes.

For Case 2, feature limits designated by the "peatland area" histograms were utilized in the application of the clustering algorithm to the entire study area (Table 4). Resulting maxima classes were then used in generation of signatures for the entire area.

For Case 3, feature limits of the "peatland areas" were utilized in clustering of the peatland feature files (Table 4). The signatures produced in this case were the result of maxima classes generated through clustering of the "peatland areas". This approach is similar in part to that taken by Fleming *et al.* (1975).

In each case-date study, classification involved assignment of scene pixels to the defined spectral classes through application of a maximum likelihood decision rule (Goldberg and Shlien 1976). Classification results were then formatted as theme files in which each spectral class was represented by a unique color.

TABLE 4. DATA SET, FEATURE LIMITS AND SIGNATURE SOURCES FOR UNSUPERVISED CLASSIFICATION CASE STUDIES

	Data Set	Feature Limits	Signature Source
Case 1	May 4,5,6,7	Entire area	Entire area
	Sept 4,5,6,7	Entire area	Entire area
	May 5,7, Sept 5,7	Entire area	Entire area
Case 2	May 4,5,6,7	Peatlands	Entire area
	Sept 4,5,6,7	Peatlands	Entire area
	May 5,7, Sept 5,7	Peatlands	Entire area
Case 3	May 4,5,6,7	Peatlands	Peatlands
	Sept 4,5,6,7	Peatlands	Peatlands
	May 5,7, Sept 5,7	Peatlands	Peatlands

A total of nine individual classifications were performed using signatures specific to 4-Band, single and multidate data sets. The classifications involved the data set/feature limit/signature source combinations listed in Table 4.

Resultant theme files were visually analysed through comparison of color monitor displays with aerial photographs, soil survey maps and ground survey data.

Tabulation of the classification results involved consideration of the total number of themes produced and number of multiple classifications within each of the nine case studies. For each case study, all themes were viewed individually and categorized as representing "peatland" (distinctly bog or fen) or "mixed" (peatland and upland) groundcover. Themes representing "other" (agricultural fields, water, cloud and cloud shadow) cover types were not included within the two major categories established, although their occurrence was noted.

The number of multiple classifications and the number of "peatland" themes and "mixed" themes were then determined for themes representing greater than 0.5% (3.1 km^2) of the total areal extent of Study Area 1.

In addition, the amount of the total study area classified and the amount of originally delineated "peatland areas" classified were determined on the basis of computer-generated classification summaries.

4.3.4 SUPERVISED CLASSIFICATION

4.3.4.1 Training Area Selection

Training areas for each major peatland type present in Study Area 1 (Table 3), were chosen on the basis of site specific field survey data. The training areas were located on color composites of single date imagery, and corresponding groups of pixels were delineated and assigned to respective training area data sets. Difficulty encountered in the location of an adequate number of pixels representative of Wooded Bog, led to the exclusion of this cover type as a training area data set.

In addition, training areas for upland cover types of aspen, conifer and mixedwoods (aspen and conifer) were also created.

Training areas were distributed over the entire study area, in accordance with Estes *et al.* (1983), who advocated dispersion of training areas throughout a region to increase the likelihood that they will be representative of a given cover type. The number of pixels utilized for each of the training areas varied according to the ability to locate representative sites. The use of 10 to 100 pixels per cover type has been suggested as the preferred range for signature generation (Lillesand and Kiefer 1979).

4.3.4.2 Signature Generation and Classification

Single date (May Band 7, 6, 5 and 4 and September Band 7, 6, 5 and 4) and multidate (May Band 7 and 5, and September Band 7 and 5) spectral signatures were generated for each of the peatland training areas identified. In addition, single date and multidate signatures were generated for the upland training areas for purposes of comparison with peatland signatures. Autocorrelation distance values, a measure of the similarity of spectral signatures, were generated for all single and multidate signatures according to the following formula:

Define C = (A+B)/2 as matrices,
then integral ((P1(X)*P2(X))**0.5) is equal to
(DET(A)**0.25)*(DET(B)**0.25)/(DET((A+B)/2)**0.5)
multiplied by
EXP(-0.25*((U-V)(INV((A+B)/2))(U-V)))
where A,B are the covariance matrices and U,V are the mean vectors (ARIES-II Manual 1982).

Based upon analysis of the spectral signatures, and their associated autocorrelation distance values, it was hypothesized that multidate peatland signatures would be more selective in the classification of peatlands than the single date signatures. To test this hypothesis, purified single date and multidate peatland signatures were utilized

in classification of Study Area 1, through application of a maximum likelihood decision rule (Goldberg and Shlien 1976).

A priori probabilities were assigned to each peatland signature utilized in classification, according to their relative predominance in the study area, but results were highly variable and not representative of cover type locations as depicted by reference data. According to Schowengerdt (1983), this procedure requires knowledge of the relative proportions of cover types prior to classification. Furthermore, the potential utility of signature extension will then depend upon the availability of prior probability information for extension areas (Strahler 1980). Consequently, *a priori* probability values were held constant at a value 0.95 for each signature utilized in classification of Study Area 1.

4.3.4.3 Signature Extension

The purified multidate signatures utilized in classification of Study Area 1 were subsequently utilized in classification of Study Area 2. *A priori* probabilities were held constant at 0.95 for each signature.

4.3.4.4 Compatibility Assessment

As information on the total areal extent of peatlands and of individual peatland cover types was not available, traditional non-site and site specific accuracy evaluations could not be implemented.

Furthermore, individual pixels could not be used as sample site locations due to the potential misregistration of geometrically corrected data (Kalensky *et al.* 1979, Todd *et al.* 1980).

Grid cells or sampling units provide an alternate basis for evaluating maps derived from different information sources. Consequently, a sampling unit approach based on map polygons was utilized to compare the results of supervised classifications with Peatland Inventory Field Maps (Turchenek *et al.* 1984). The latter were derived from aerial photograph interpretations and field surveys.

Classification results for Study Area 1, the source of the training area signatures and Study Area 2, the signature extension test segment, were generated as 1:50,000 scale thematic maps. Peatland Inventory Field Maps for both study areas were acquired on clear acetate at 1:50,000 scale and subsequently registered with the thematic maps. Map polygons representing each of the major peatland types, but exclusive of training area sites, were randomly selected on the Peatland Inventory Field Maps and included:

1. Coniferous Fens - consisting of both Treed Fens and Lightly Treed Fens;
2. Shrubby Fens;
3. Sedge Fens; and
4. Forested Bogs.

The relative proportions of individual themes occurring within each polygon, as well as the proportions unclassified, were visually estimated and tabulated as decile distributions. This procedure enabled an objective comparison of the map polygon descriptions derived from spectral characteristics of ground cover with those derived from interpretations of vegetation associations and landforms.

5. RESULTS and DISCUSSION

5.1 IMAGE ENHANCEMENT

5.1.1 SINGLE DATE DATA

Simulation of color infrared imagery using piece-wise stretched data (Appendix 2), provided the most favorable imagery for discrimination of peatland and upland cover types, for both May and September imagery.

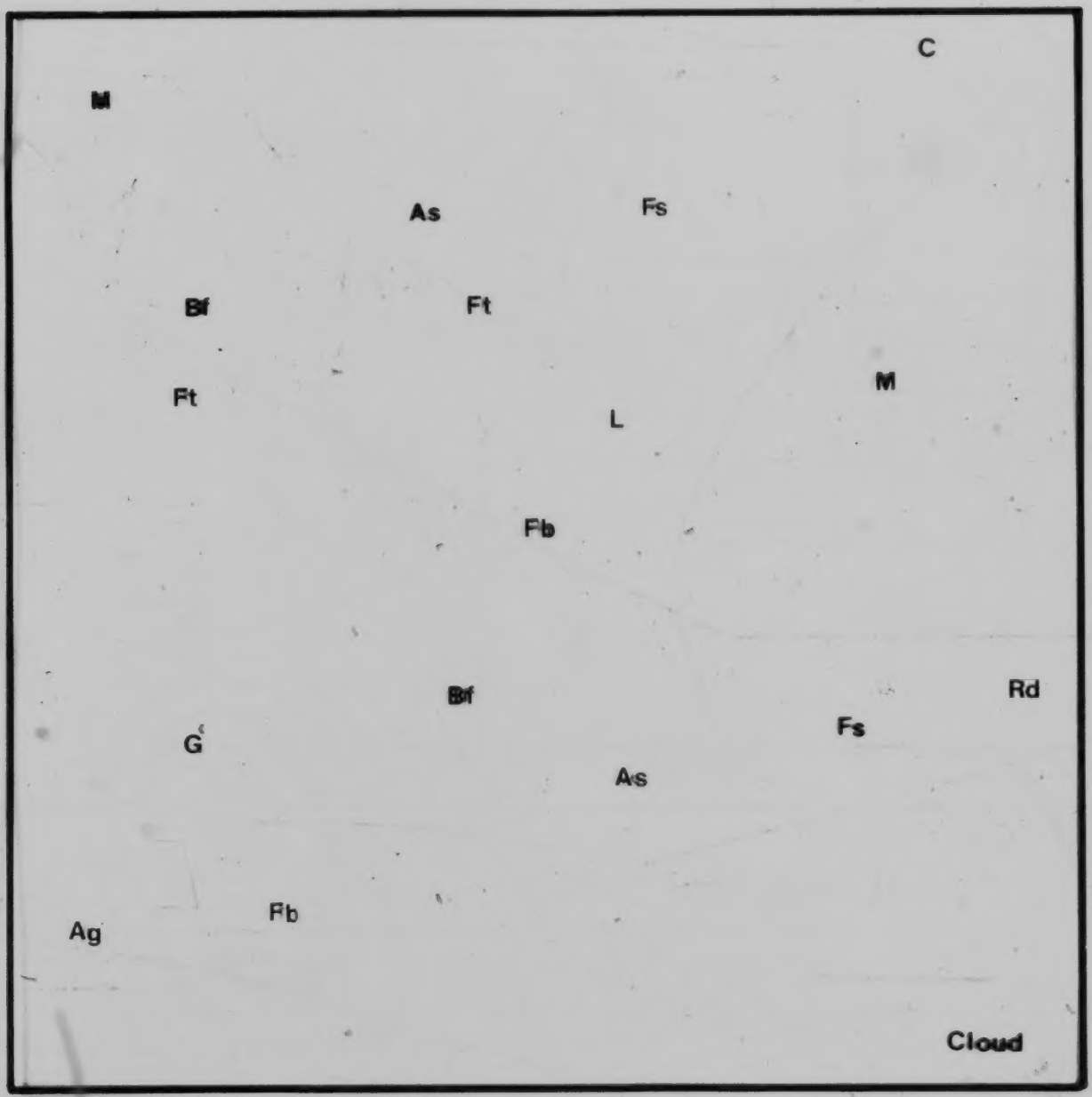
These images were produced by projection of bands 7, 5 and 4 through red, green and blue light, respectively, for each date of imagery. This color additive viewing procedure provided optimal contrasts between ground cover types relative to the images produced using the methods proposed by Singhroy and Bruce (1981) and Tomlins and Thompson (1981). The relatively poor visual quality of the images produced using these latter viewing procedures was likely due to differences in the specific dates of imagery and environments studied. Singhroy and Bruce (1981) utilized October imagery of The Pas region in Manitoba, while Tomlins and Thompson (1981) utilized July imagery of the Fraser River estuary. The inability to replicate their results suggests that a particular color additive viewing procedure is quite specific to the date of imagery, the seasonal characteristics of ground cover types and the geographic region being studied. Consequently, color additive viewing tends to be a very subjective procedure.

5.1.1.1 May Imagery

The color composite image of piece-wise stretched Bands 7, 5 and 4 (Appendix 2.1) projected through red, green and blue light respectively, is presented for Study Area 1 (Plate 4), accompanied by an interpretive key (Table 5). This color composite was suitable for the stratification of broad cover classes: peatlands, upland forests, water bodies, agricultural lands and roads.

The color renditions of various ground cover types were the result of the additive effects of illuminating individual bands of radiometric data with colored light. In Plate 4, regions represented by pixels having high radiometric values (high reflectance) in all three bands of data appear white-toned, due to combination of the three colors of light used in projection of the image. Associated cover types include sedge fens (composed mainly of dry sedges in the springtime), crops or pasture lands (crop or forage residues) and road allowances and gas well sites (grasses). Distinctions between these cover types were made on the basis of color rendition, spatial distribution and geometry.

Regions of peatlands varied from orange-rust to light blue-green. Associated cover types include Treed Fens and Lightly Treed Fens, both of which are characterized by moderately high radiometric values in the visible red (projected as green light) and visible green (projected as blue light), in combination with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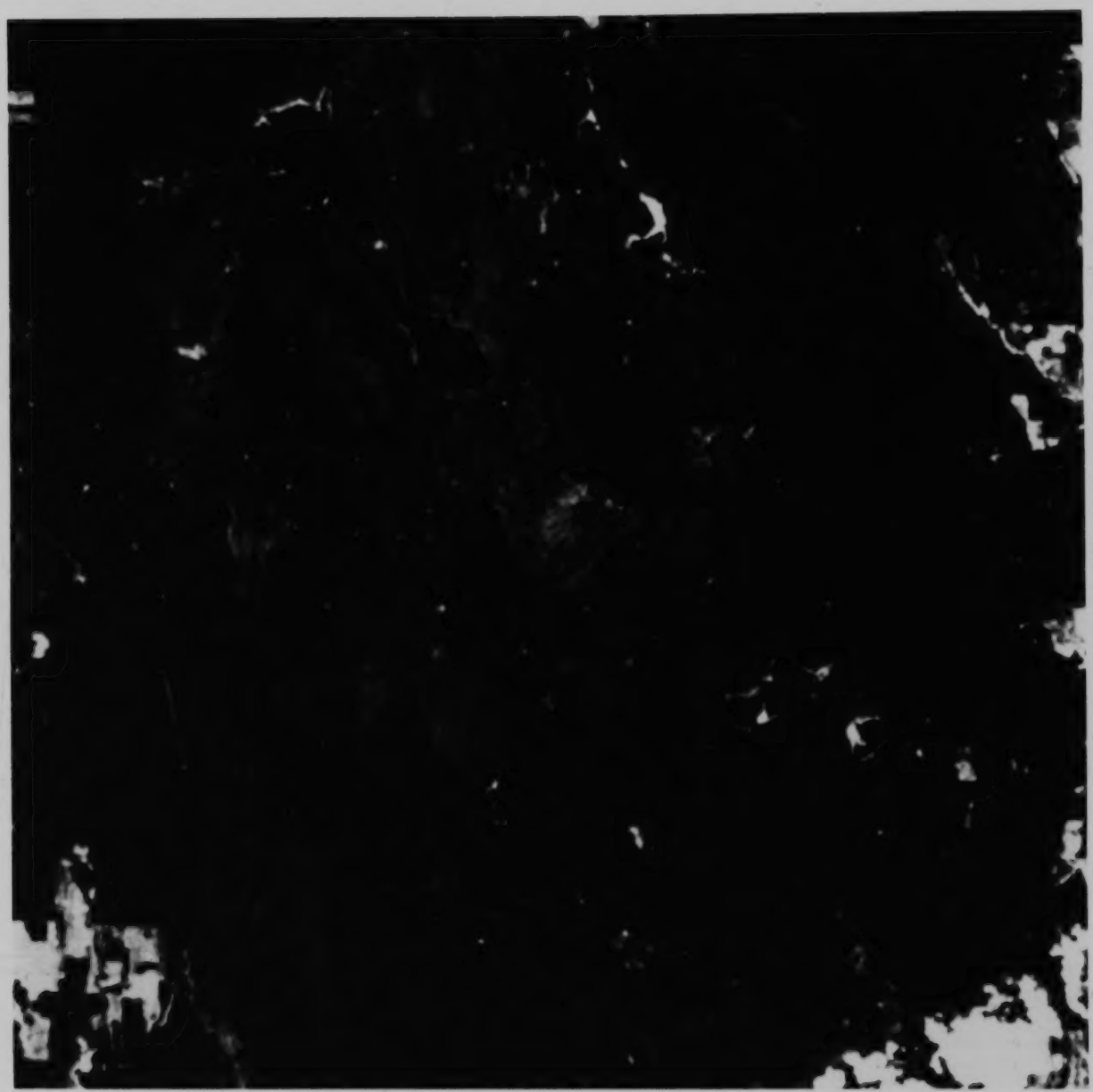


Plate 4. Color-enhanced May image of Study Area 1.
(Approx. scale 1:140,600)
Consult Table 5 for interpretive key.

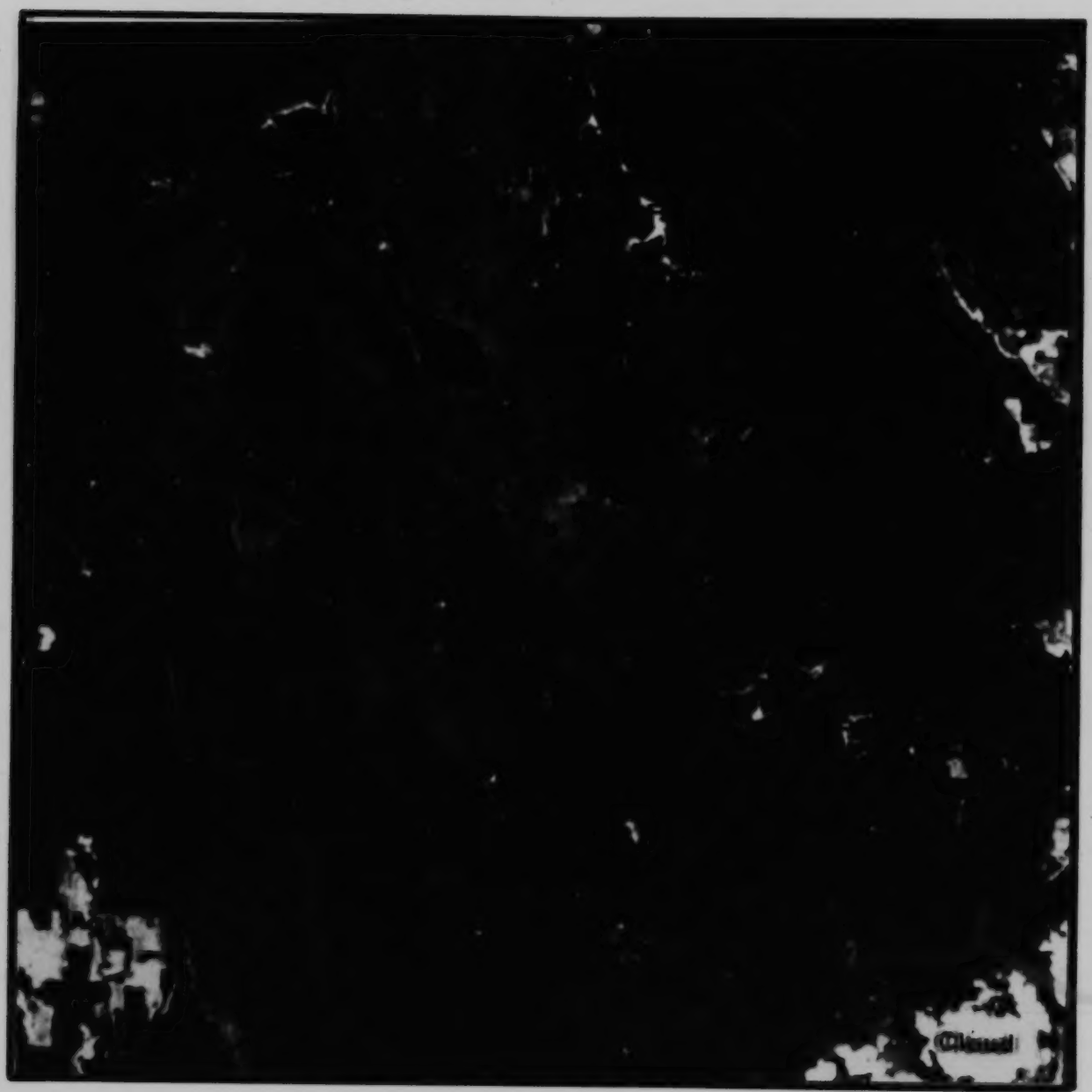


Plate 4. Color-enhanced May image of Study Area 1.
(Approx. scale 1:140,600)
Consult Table 5 for interpretive key.

TABLE 5. INTERPRETIVE KEY FOR COLOR ENHANCED MAY IMAGERY

Cover Type	Symbol	Color Rendition	Geometric Configuration
Peatlands:			
Sedge fens:	fs	White	Lake perimeters, drainage channels
Treed fens:	ft	Orangey rust	
Shrub fens:	fb	Light blue green to light orange	Curvilinear to string patterns
Forested bogs:	Bf	Dark rust	
Uplands:			
Aspen forest:	As	Medium blue-green	Curvilinear to string patterns
Conifer forest:	C	Dark rusty green	
Mixed aspen and Conifer:	M	Mottled blue-green and rusty-green	
Water:			
Lakes:	L	Dark blue-black	Lakes
Rivers:	R	Dark royal-blue	Rivers
Cultivated lands: Crop or pasture:	Ag	White to pale orangey-pink	Rectangular
Roads and	Rd	White to light grey	Linear to curvilinear
Gas well sites:	G		Small, rectangular regions

high infrared reflectance (projected as red light). Shrubby Fens, however, ranged in color rendition from light blue-green (very low amounts of foliage and therefore low infrared reflectance) to light orange (higher infrared reflectance associated with ericaceous shrub foilage).

Dense conifer cover, such as that of Forested Bogs and upland forests, appeared dark rust to rusty-green in color rendition, due to combined low radiometric values for the infrared and relatively high values for the visible red and green portions of the spectrum. In contrast, upland forests dominated by aspen appeared medium blue-green due to the relatively lower infrared reflectance characteristic of the defoiliated condition at this time of year. Within the upland regions mottled regions of dark rusty-green were indicative of coniferous associations.

Water bodies were recognized on the basis of their low reflectance properties in all bands, which rendered them as dark blue-black regions, as well as by characteristic geometry. Fallow fields also appeared as dark greenish-black regions, and were distinguished on the basis of their rectangular geometry.

Overall, preliminary stratification of peatlands from upland forests was possible using a color-infrared simulation of May spectral data, coupled with recognition of phenological characteristics and geometry

of the respective cover types. Further stratification of peatland regions into specific cover types required accessory information derived from site specific field surveys.

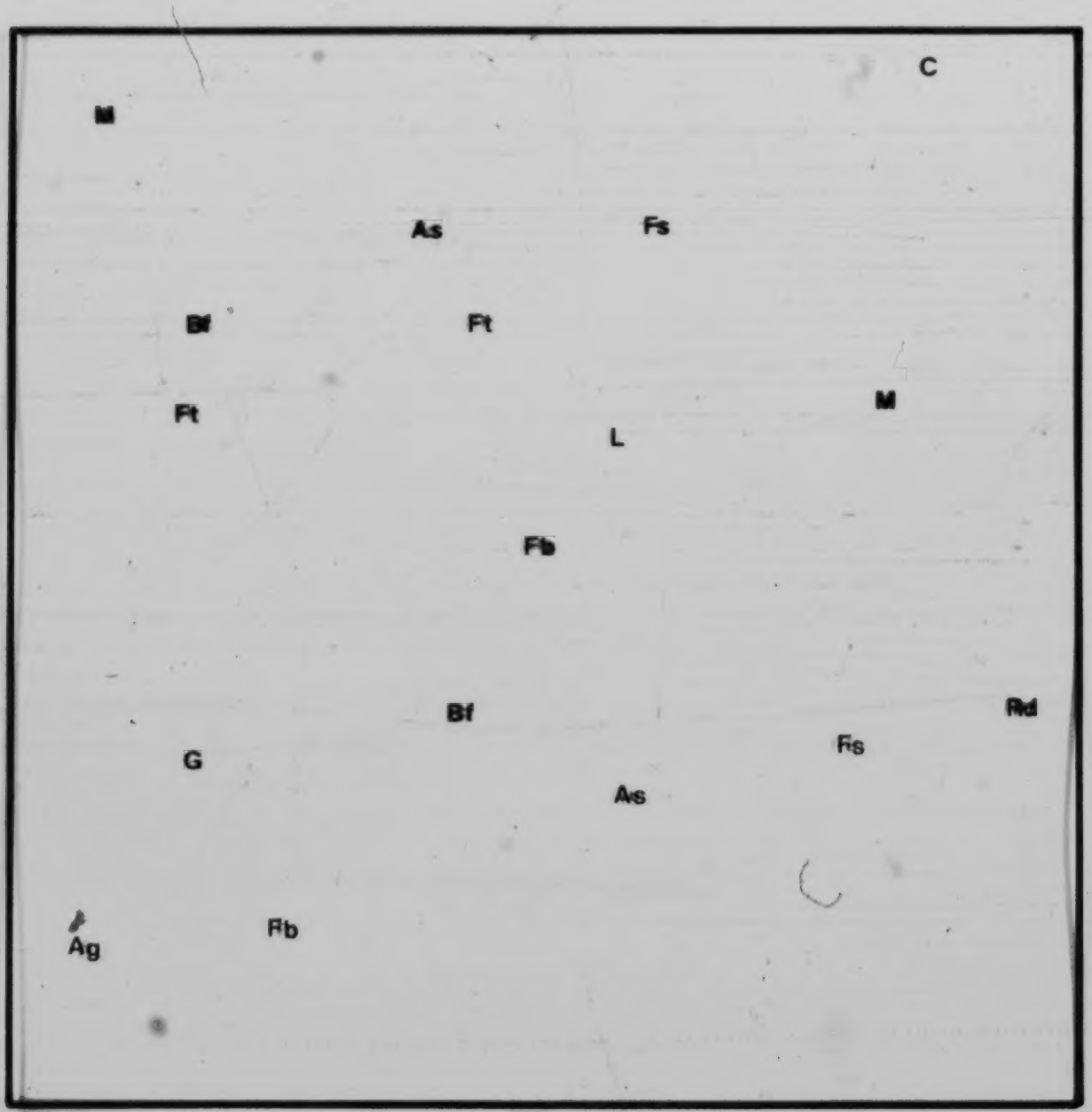
5.1.1.2 September Imagery

Plate 5 is a simulated color-infrared image consisting of piece-wise stretched September data (Appendix 2.2) and is accompanied by an interpretive key (Table 6).

The central portion of the image is covered by a thin layer of haze, which appears white to grey in color, the result of the combined reflectance of infrared, visible red and visible green radiation.

The image is dominated by red tones, the result of many pixels having relatively high radiometric values in the infrared band (Band 7). This is representative of the phenological condition of the deciduous and graminoid vegetation associated with both peatlands and uplands in early autumn. Upland aspen forests, deciduous shrubs, tamarack, grasses and sedges are characterized by relatively high infrared reflectance and low visible reflectance during periods of active growth. Consequently, these cover types appear dominantly as red to rust tones (Table 6).

In contrast, coniferous cover types have relatively lower infrared reflectance characteristics, but also reflect both visible red and green portions of the


C
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Ft
M
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Ag

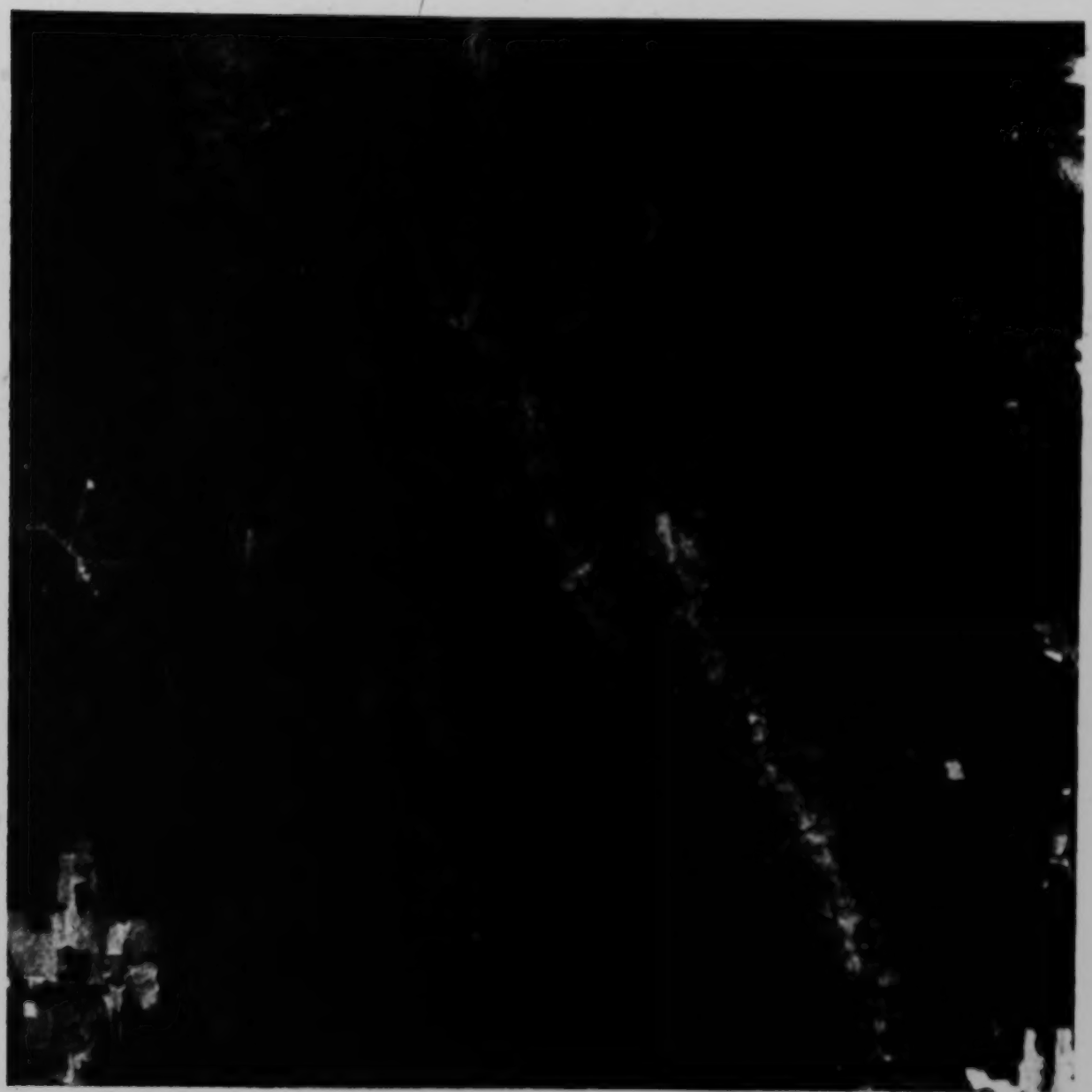


Plate 5. Color-enhanced September image of Study Area 1.
(Approx. scale 1:140,600)
Consult Table 6 for interpretive key.

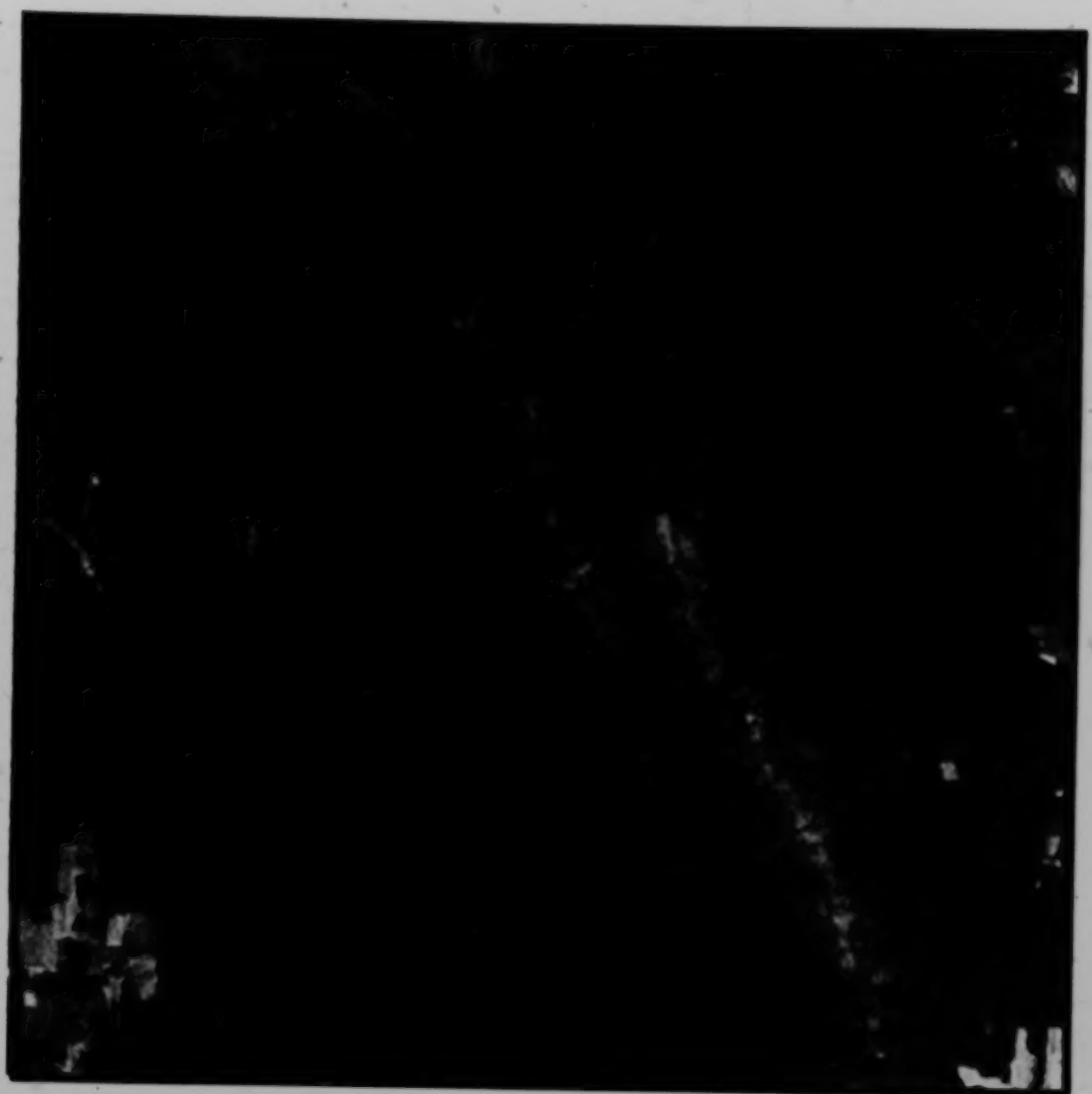


Plate 5. Color-enhanced September image of Study Area 1.
(Approx. scale 1:140,600)
Consult Table 6 for interpretive key.

TABLE 6. INTERPRETIVE KEY FOR COLOR ENHANCED SEPTEMBER IMAGERY

Cover Type	Symbol	Color Rendition	Geometric Configuration
Peatlands:			
Sedge fens:	Fs	Light orangey-rust	Lake perimeters, drainage channels
Treed fens:	Ft	Orangey rust to yellowish-red	
Shrub fens:	Fb	Rusty-yellow to yellowish green	Curvilinear to string patterns
Forested bogs:	Bf	Dark greenish black	
Uplands:			
Aspen forest:	As	Rusty-red	Curvilinear to string patterns
Conifer forest:	C	Dark greenish black	
Mixed aspen and Conifer:	M	Mottled rusty-red and greenish-black	
Water:			
Lakes:	L	Dark blue-black	Lakes
Rivers:	R	Dark royal blue	Rivers
Cultivated lands: Crops or pasture:	Ag	Light pink to orangey-white	Rectangular
Roads and	R	White to light blue	Linear to curvilinear
Gas well sites:	G		Small, rectangular

spectrum. Consequently, coniferous cover appears dark greenish-black (Plate 5). Regions characterized by mottles of rusty-red and greenish-black are indicative of conifers interspersed with deciduous cover, a condition typical of both peatlands and uplands of the study areas.

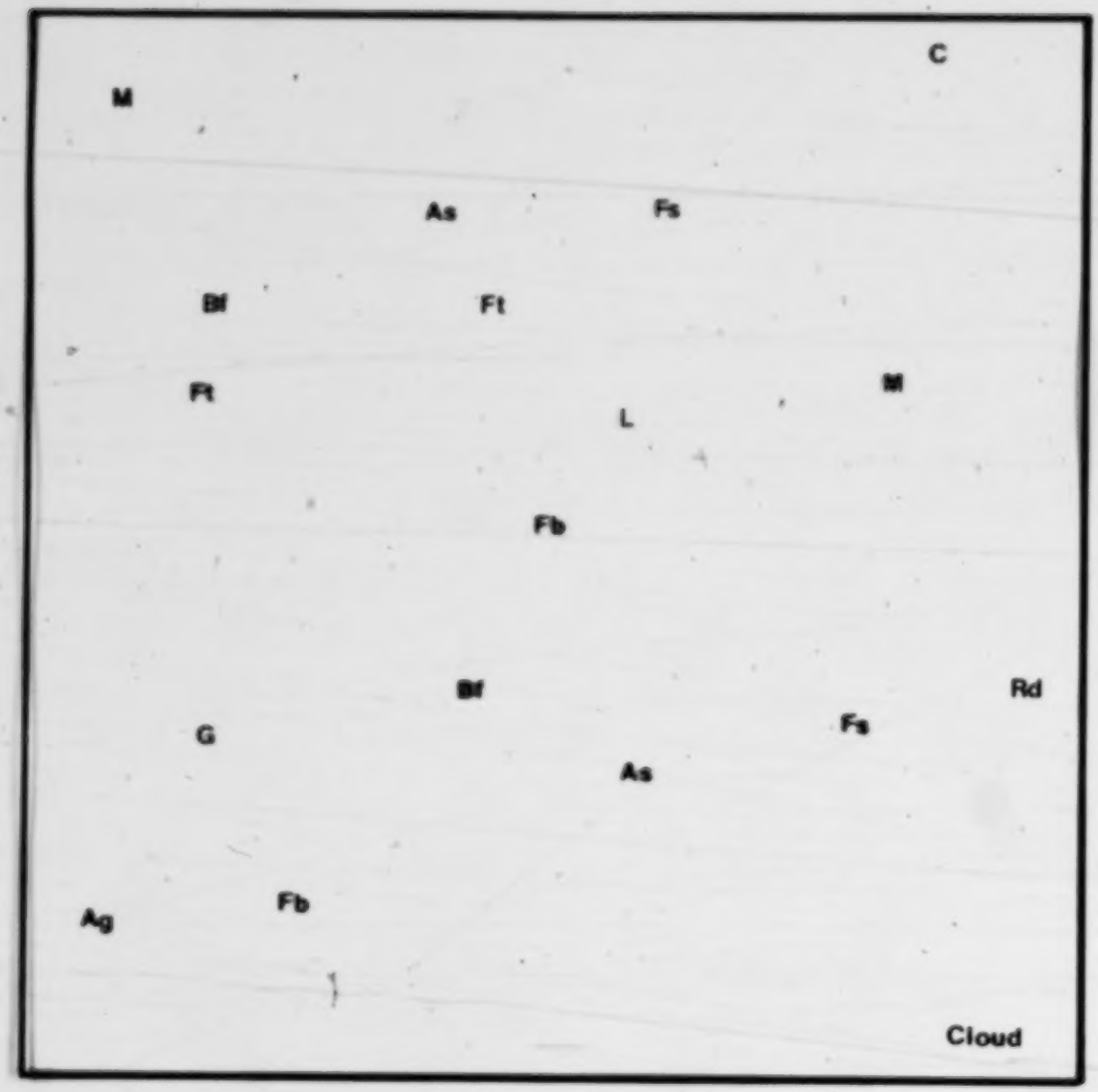
Differentiation of peatlands and uplands in the September imagery was more dependent on identification of geometry and relative locations of the respective cover types, and therefore required the use of ancillary reference data (aerial photographs and field survey information) to confirm the broad cover types.

Of the single date imagery, May images were preferred to September images for preliminary interpretations of both study areas.

5.1.2 MULTIDATE DATA

Optimal contrast of peatland and upland regions, for both study areas, was achieved through projection of piece-wise stretched May Band 7, September Band 7 and May Band 4 data through red, green and blue light, respectively (Plates 6 and 7). An interpretive key for these multidate composites is presented in Table 7.

For these images, the color renditions of the various ground cover types may be explained by considering the color additive effects. Regions characterized by high infrared reflectance in both the May and September imagery appear


C
M
As
Fs
Bf
Ft
Ft
M
L
Fb
Bf
Rd
G
Fs
As
Fb
Ag
Cloud

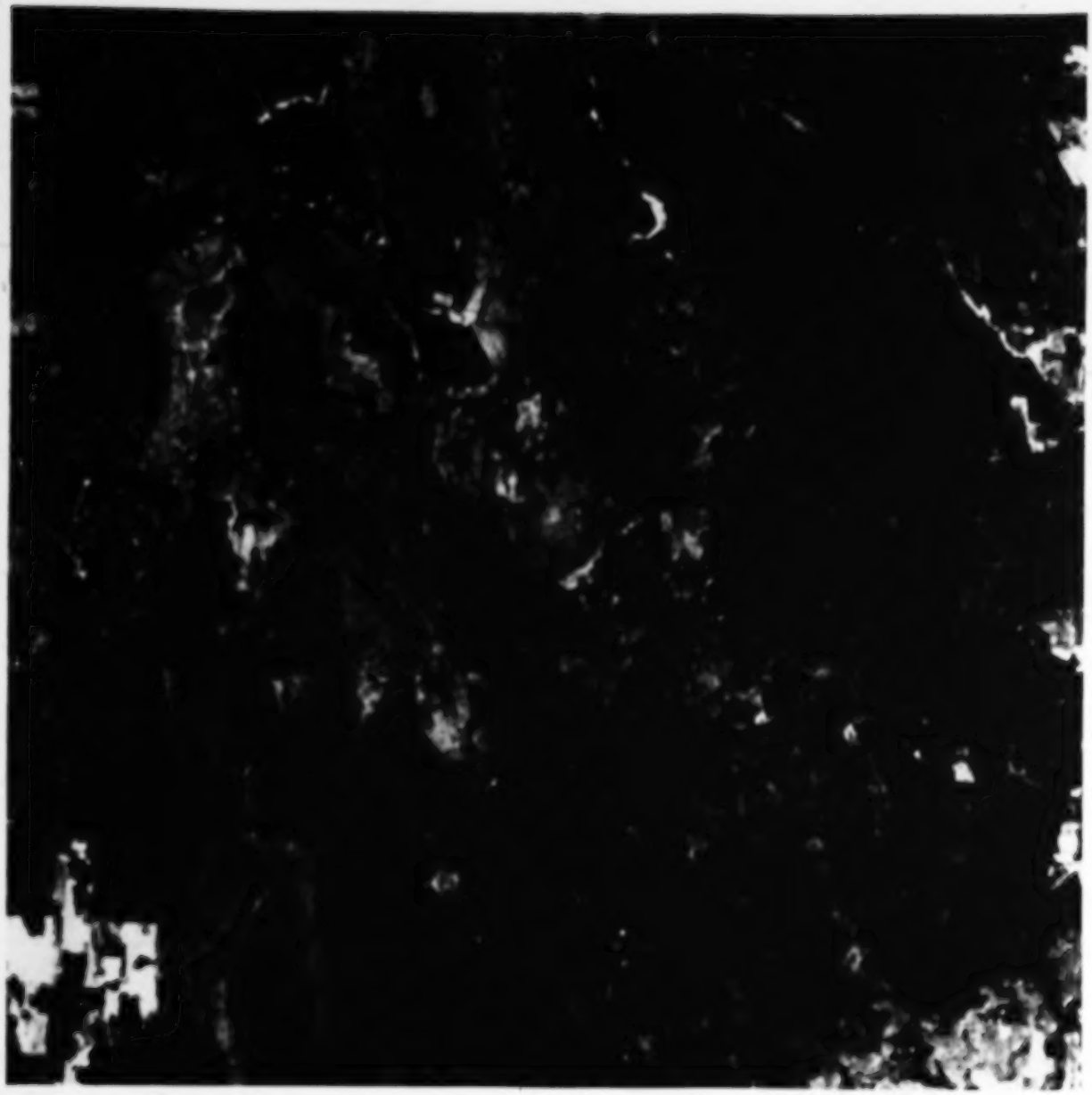


Plate 6. Color-enhanced Multidate image of Study Area 1.
(Approx. scale 1:140,600)
Consult Table 7 for interpretive key.

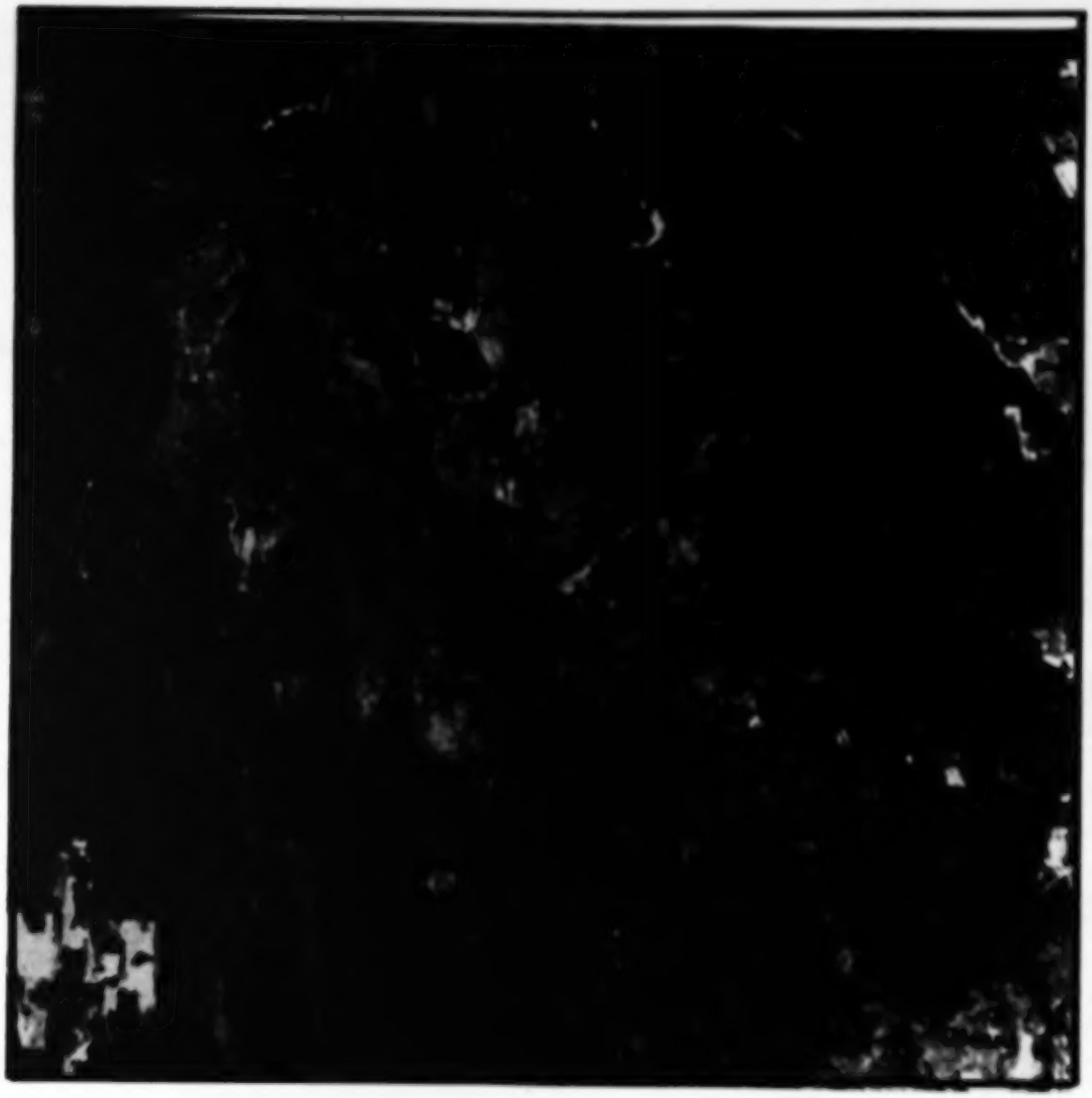
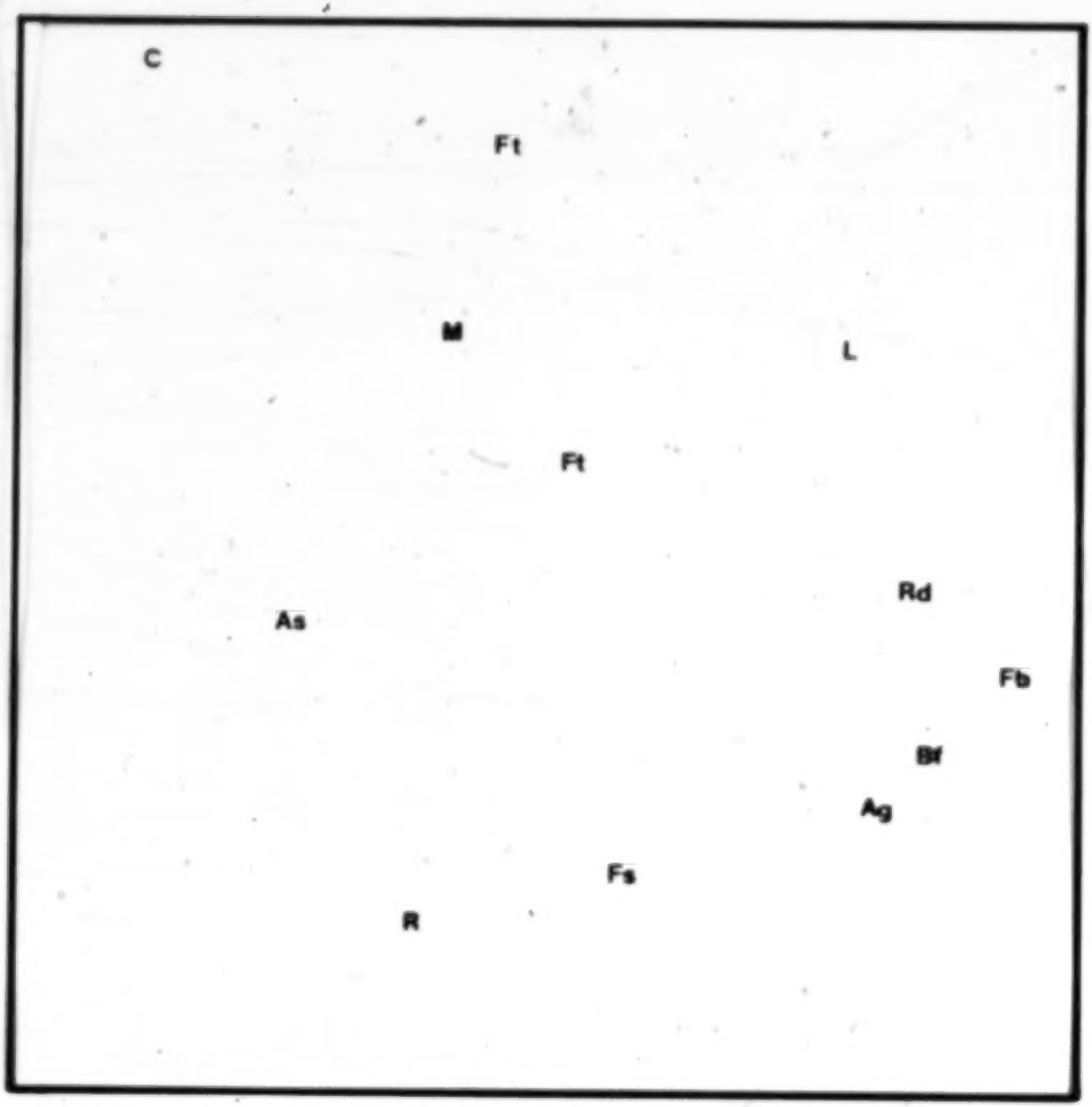


Plate 6. Color-enhanced Multidate image of Study Area 1.
(Approx. scale 1:140,600)
Consult Table 7 for interpretive key.

TABLE 7 INTERPRETIVE KEY FOR COLOR-ENHANCED MULTIDATE IMAGERY

Cover Type	Symbol	Color Rendition	Geometric Configuration
Peatlands:			
Sedge fens	Fs	Magenta to white	Lake perimeters, drainage channels
Treed fens	Ft	Yellow to orangey rust	
Shrub fens	Fb	Magenta to greenish yellow	Curvilinear to string patterns
Forested bogs	Bf	Rust	
Uplands:			
Aspen forest	As	Bright green	Curvilinear to string patterns
Conifer forest	C	Rust to dark rusty green	
Mixed aspen and Conifer	M	Mottled green and dark rust	
Water:			
Lakes	L	Dark blue-black	Lakes
Rivers	R	Dark royal blue	Rivers
Cultivated lands: Crops or pasture	Ag	White to yellow	Rectangular
Roads and Gas well sites	R G	White to yellowish grey	Linear to curvilinear. Small, rectangular regions


C
Ft
M
L
Ft
Rd
As
Fb
Bf
Ag
Fs
R

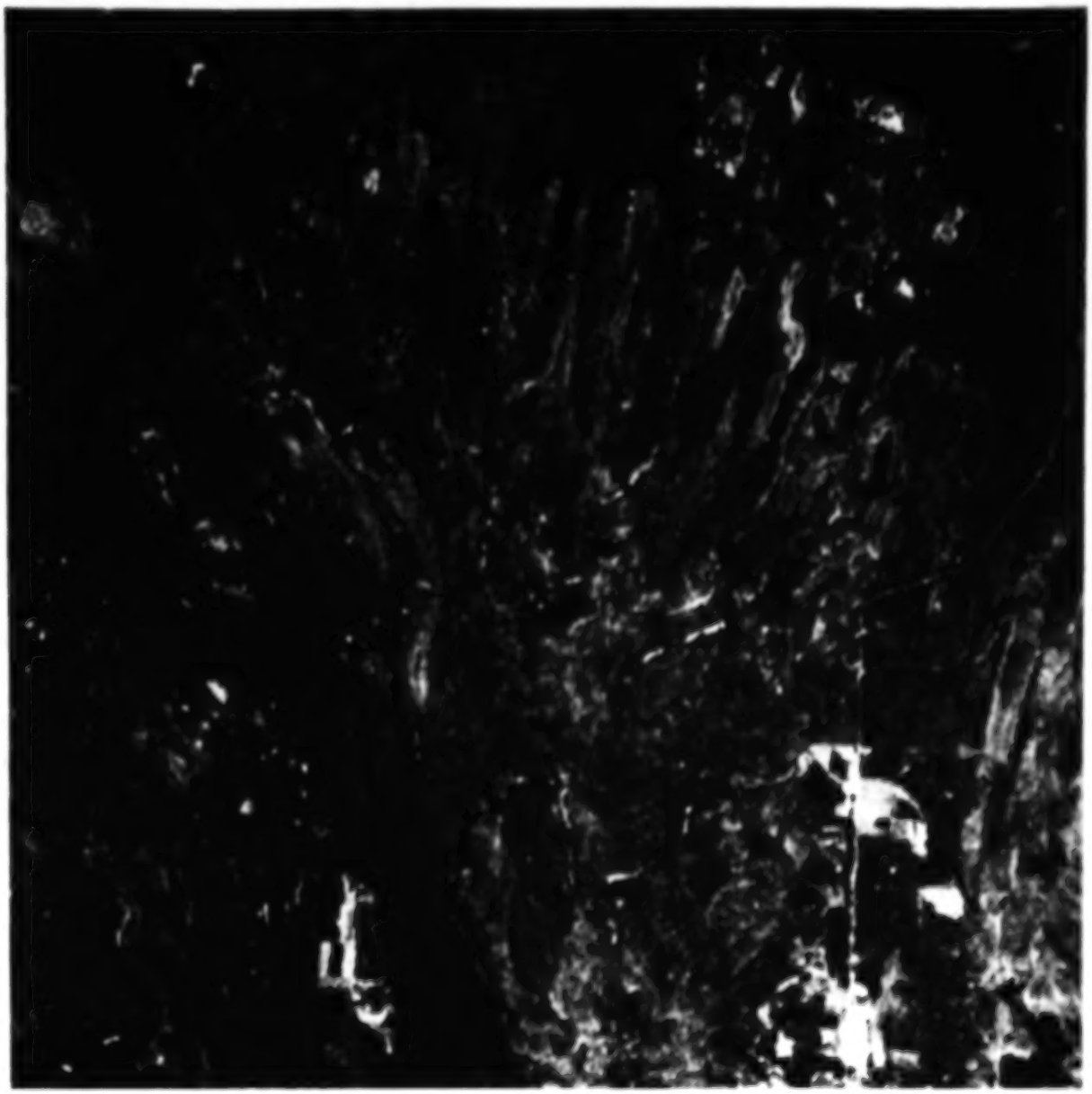


Plate 7 Color-enhanced Multidate image of Study Area 2
(Approx scale 1:140,600)
Consult Table 7 for interpretive key

Plate 7 Color-enhanced Multidate image of Study Area 2.
(Approx. scale 1:140,600)
Consult Table 7 for interpretive key.

yellow to orangey-rust in color. These regions are predominantly peatlands characterized by both deciduous and coniferous vegetation cover types. White to yellowish-white areas are representative of sedges, grasses and agricultural crops that reflect highly in the infrared on both dates and in visible green in May. The magenta color associated with sedges and ericaceous shrubs is due to red and blue light projected at nearly similar intensities, as the result of high infrared and visible green reflectance in May, but relatively lower infrared reflectance in September.

Aspen forests of Upland regions appear dominantly green in color rendition, the result of low infrared reflectance in May (defoliated condition) and contrastingly high infrared reflectance in September (abundant foliage). Regions of deciduous shrubs, such as Shrubby Fens, appear greenish-yellow to magenta in color rendition due to the phenological and spectral characteristics deciduous and graminoid vegetation. In contrast, the lower infrared reflectance of conifers produces mottled regions of dark rust to dark rusty-green in both peatland and upland regions.

Low infrared reflectance typical of water bodies results in a dark blue-black color for lakes and rivers.

Overall, the most favorable imagery for visual interpretation was produced through color additive viewing of multidate data. Resultant color renditions provided optimal contrast of peatland and upland cover types, useful

for preliminary stratification of both study areas. With respect to the subjective nature of visual interpretations, single date May imagery provided a more contrasting image relative to the September data, for the particular color additive viewing technique employed.

As with any color enhancement procedure, a major drawback in use involves the need for recognizing and learning new color renditions for ground cover types (Schubert *et al.* 1977). Furthermore, color renditions depicted on hardcopy imagery may not necessarily represent the color renditions obtained on the color monitor, as the result of laboratory processing of film. This may be of consequence when only subtle differences in color renditions of cover types can be achieved.

5.2 UNSUPERVISED CLASSIFICATION

5.2.1 HISTOGRAM ANALYSIS

Distinct variations between the feature limits of the entire study area and of the generalized "peatland" areas were observed (Table 8). The compression of the range of each set of feature limits corresponding to the "peatland" feature files was most prominent for the infrared bands (6 and 7), and was attributed to the exclusion of water bodies, agricultural fields, cloud and cloud shadows. These cover types are typified by radiometric values associated with the low and high ends of the radiometric scale, respectively.

The feature limit ranges for both the entire area and the "peatland" areas were consistently wider for the May data than for the September data (Table 8). This indicates that for the particular study area, spectral variation in cover types is more pronounced in the spring relative to the autumn imagery. This observation was also made during examination of single date color-enhanced imagery, in which May imagery provided more contrast in cover types relative to the September imagery.

5.2.2 CASE STUDIES

Through the application of the clustering algorithm to 4-band data sets (Table 4), it was observed that as histogram bin sizes (width of histogram partitions) increased, the number of resultant maxima classes decreased.

TABLE 8 HISTOGRAM FEATURE LIMITS USED IN UNSUPERVISED CLASSIFICATION

	Radiometric Values of Histogram Limits	
	Entire Area	Peatland Area
May Imagery		
Band 7	0 - 110	43 - 103
Band 6	10 - 100	44 - 93
Band 5	20 - 80	29 - 80
Band 4	20 - 60	28 - 57
September Imagery		
Band 7	0 - 85	35 - 79
Band 6	0 - 80	35 - 67
Band 5	0 - 45	21 - 39
Band 4	20 - 40	21 - 39

The number of maxima classes also decreased with compression of the spectral band histogram limits of delineated "peatland areas". In turn, the total number of themes (spectral classes) decreased in each subsequent case-date study (Table 9).

Overall, clustering of spring data (May Bands 4,5,6 and 7) produced the greatest total number of themes within each case study (Table 9). This is indicative of a greater variation in spectral response of ground cover types at this time of year. This trend persisted when themes, which individually represented less than 0.5% (3.1 km²) of the entire study area, were excluded (Table 9). These themes were generally small, widely scattered occurrences over the entire study area that would likely be removed in any post-classification filtering.

The relatively large number of "mixed" themes in comparison with distinct "peatland" themes from both spring and autumn data is indicative of the inherent variability in the vegetation density and composition of the indigenous peatland types. This variability, notably in percent tree cover, resulted in classification of upland conifers (jack pine and white spruce) and peatland conifers (black spruce and tamarack) within the same themes. Spectral confusion was also observed to occur between deciduous uplands and deciduous peatlands. Field surveys undertaken in the summer of 1983 (Turchenek *et al.* 1984) confirmed compositional heterogeneity of several bogs and fens in which vegetation

TABLE 9. SUMMARY OF CLASSIFICATION RESULTS FOR UNSUPERVISED CLASSIFICATION CASE STUDIES

	Total No. Themes	No. Multiple Classifications	Themes >0.5% of Entire Area				% Area Classified	
			Total No.	Multiple Classifications	No. Peatland	No. Mixed	Total Area	Peatland Areas
MAY								
Case 1	29	10	14	3	2	8	90	91
Case 2	28	12	12	0	2	10	58	57
Case 3	14	0	13	0	2	11	28	56
SEPTEMBER								
Case 1	18	5	11	0	0	9	91	95
Case 2	6	0	6	0	0	6	48	59
Case 3	6	0	6	0	0	6	34	46
MAY + SEPTEMBER								
Case 1	18	0	8	0	0	4	58	32
Case 2	8	0	3	0	1	1	10	14
Case 3	7	0	5	0	2	3	16	53

Case 1 = Entire Area Feature Limits + Entire Area Signatures.

Case 2 = Peatland Feature Limits + Entire Area Signatures.

Case 3 = Peatland Feature Limits + Peatland Signatures.

species and density ranged notably within and between sampling sites.

Multiple classifications were observed to occur in the spring data (Case 1 & 2) and autumn data (Case 1) when all resultant themes were considered (Table 9). For those themes representing greater than 0.5% of the total area, multiple classifications occurred in the spring data (Case 1) only. These multiple classifications were attributed to the occurrence of several "mixed" themes relative to the distinct "peatland" themes. In application of clustering procedures, there exists potential for the occurrence of misclassification and/or multiple classification when one theme is representative of several cover types, or if several themes represent a single cover type. Studies utilizing clustering have reported confusion between coniferous and deciduous cover (Fleming *et al.* 1975, Pitblado and Amiro 1982), as well as between peatlands and nonpeatlands (Tarnocai and Kristof 1976, Beaubien 1979, Wickware 1979, Schreier *et al.* 1982, Dixon *et al.* 1983). In these studies, multiple classifications and misclassifications were most often attributed to the diversity and variable density of vegetation associations and the occurrence of transition areas (Table 2).

Alteration of feature limits from those of the "entire area" to those of the generalized "peatland areas" (Table 8) resulted in several trends within both single date and multidate data. Firstly, "peatland area" feature limits

utilized in the clustering procedure (Case 1) resulted in the generation of a fewer number of signatures than did the "entire area" feature limits. Secondly, upon classification of the study area with signatures generated specific to each case, a smaller percentage of the study area was classified whenever "peatland area" signatures were utilized (Table 9). These observations were attributed to the exclusion of water bodies, agricultural fields, roads, gas well sites and cloud shadows in the band histograms for the peatland areas.

Peatland feature limits applied to clustering and subsequent signature generation of the entire study area (Case 2) resulted in fewer signatures, with a smaller percentage of the total area being classified (Table 9). The latter result was anticipated in view of attempting to prevent generation of signatures that were not representative of peatland cover types.

Similarly, fewer signatures were generated through the clustering of delineated "peatland areas" (Case 3), and resulted in classification of a smaller percentage of total area relative to Case 1 (Table 9). This was indicative of signatures having been restricted to the ground cover associated with delineated peatland types. The greater number of "mixed" themes, 11 and 6, for May and September, respectively, relative to distinct "peatland" themes, is indicative of variability in spectral characteristics of cover types. In this study, spectral variability may be attributed to the observed heterogeneity in the type,

density and distribution of vegetation associated with the peatlands of this region.

Within the peatland areas, altering feature limits from those of the entire area to those of the generalized "peatland areas" (Table 8) reduced the total amount of the study area classified (Case 1 vs Case 2). For single date data, Case 3 resulted in a further reduction in the proportion of peatland area classified for single date data, whereas with multidate data, Case 3 resulted in an increase (Table 9).

These results may be explained by considering both the spectral characteristics of the ground cover and the workings of the clustering algorithm utilized. The signatures which served as a basis for the themes were relatively specific to particular cover types and percent cover classes. The unclassified areas did not conform spectrally to the statistical parameters of the classes defined by the algorithm, indicative of great diversity in vegetation composition, the possibility of confounding boundary pixels, and limitations of the clustering algorithm.

Letts (1978) provided a comprehensive discussion of the search for "local maxima" in pixel frequency histograms that tends to exclude pixel counts that are not immediately recognized as maxima. It is possible that the spectral and spatial variability of the ground cover produced spectral responses that were not recognized as local maxima by the

algorithm, and therefore not utilized in the production of maxima classes for "peatland" signature generation. This is supported by the reduced numbers of maxima classes, signatures and themes (Table 9) for both single date and multidate case studies.

5.3 SUPERVISED CLASSIFICATION

5.3.1 SINGLE DATE SIGNATURES

Preliminary examination of the radiometric values of the single date signatures (Tables 10 and 11) revealed the potential for spectral confusion of peatland and upland cover types. The occurrence of numerically similar means, coupled with relatively large standard deviations indicated potential overlap of signatures, which would result in either multiple classifications or misclassifications of cover types.

May signatures (Table 10) demonstrated overlap of Treed Fen, Lightly Treed Fen and Shrubby Fen signatures. This could be the result of both species composition and spatial distribution of associated cover types. Tamarack and/or black spruce cover is associated with both Treed Fens and Lightly Treed Fens (Table 3). Depending on the spatial distribution of these cover types, associated pixels may be spectrally similar. Furthermore, fen complexes within the study region are often characterized by a gradation of tree cover (Plate 1), which contributes to the occurrence of

TABLE 10 RADIOMETRIC VALUES OF MAY SPECTRAL SIGNATURES GENERATED FOR SUPERVISED CLASSIFICATION

	Band 7		Band 6		Band 5		Band 4	
TRAINING AREA	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Treed Fen	70.30	9.50	64.42	8.39	41.05	1.29	35.45	1.67
Lightly Treed Fen	70.42	3.69	63.88	3.09	41.84	1.81	34.33	1.32
Shrubby Fen	73.63	2.80	65.90	3.71	54.00	3.72	41.69	2.34
Sedge Fen	89.59	8.25	81.94	8.32	72.84	6.76	51.21	4.14
Forested Bog	79.37	3.41	70.55	3.16	39.51	1.75	34.50	1.51
Aspen	53.88	4.58	52.55	3.70	41.57	3.60	35.23	2.02
Mixedwoods	55.86	4.25	53.61	4.05	39.47	3.93	34.47	2.15
Upland Conifer	54.35	5.40	52.92	5.02	38.14	7.20	33.75	3.15

TABLE 11. RADIOMETRIC VALUES OF SEPTEMBER SPECTRAL SIGNATURES GENERATED FOR SUPERVISED CLASSIFICATION

	Band 7		Band 6		Band 5		Band 4	
TRAINING AREA	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Treed Fen	56.38	3.04	53.42	4.40	31.92	2.89	30.05	2.58
Lightly Treed Fen	58.63	3.42	54.41	2.83	29.93	1.10	28.07	1.18
Shrubby Fen	58.31	3.57	53.78	4.43	34.44	2.09	30.01	1.67
Sedge Fen	59.39	8.41	53.77	8.26	33.18	1.67	29.31	1.66
Forested Bog	55.63	3.69	52.47	3.44	30.27	1.82	27.77	1.07
Aspen	65.66	5.76	60.60	4.45	29.37	1.69	28.80	1.50
Mixedwoods	52.85	5.80	50.27	4.93	27.74	1.77	26.75	1.37
Upland Conifer	42.18	4.48	42.63	4.12	26.76	3.38	26.32	2.09

boundary pixels.

Understory vegetation of tree covered fens is similar in composition to that of Shrub Fens (Table 3), indicative of similarity in spectral characteristics, and potential spectral confusion during classification procedures.

Sedge Fens are relatively unique in their May signatures compared to other cover types. This suggests that identification of Sedge Fens would be better accomplished using May signatures.

Forested Bog signatures overlapped with Treed Fen signatures in both May and September data (Tables 10 and 11). This could be attributed to similarity in the amount of tree cover, as well as in species composition (Table 3). Consequently, spectral confusion of these cover types was anticipated.

Evaluation of spectral signatures for three upland cover types (aspen, mixedwoods and conifer), indicated potential for spectral confusion among these cover types for both the May and September data. In addition, potential for confusion of uplands with peatlands was anticipated for September signatures, and to a lesser extent for May signatures.

Autocorrelation distance (ACD) values revealed the amount of correlation between signatures, and the potential for spectral confusion during classification. According to the ARIES-II Manual (1984), the larger the calculated autocorrelation distance value, the more distinct are the respective signatures, such that:

1. An ACD value of 0 indicates 100% correlation between signatures;
2. An ACD value of 0.5 indicates 50% correlation;
3. An ACD value of 1.0 indicates 30% correlation; and
4. An ACD value of 2.0 indicates 10% correlation.

Comparison of the ACD values for both sets of single date signatures (Tables 12 and 13) indicated that May signatures were relatively more distinct spectrally than the September signatures. This was demonstrated by a trend in overall larger ACD values for May signatures relative to September signatures. This trend suggested that spectral separation of cover types would be better achieved using May signatures rather than September signatures in subsequent classifications.

The utility of May data relative to September data was observed earlier in both image enhancement and unsupervised classification studies.

TABLE 12 AUTOCORRELATION DISTANCE VALUES FOR MAY SIGNATURES

PEATLAND COVER TYPE	AUTOCORRELATION DISTANCE VALUES							
	Treed Fen	Lightly Treed Fen	Shrubby Fen	Sedge Fen	Forested Bog	Aspen Uplands	Mixedwood Uplands	Conifer Uplands
Treed Fen	0 000	0 629	7 395	11 596	1 293	2 275	1 720	2 148
Lightly Treed Fen		0 000	6 867	20 143	3 394	8 012	4 572	5 331
Shrubby Fen			0 000	2 915	10 646	6 670	7 197	5 091
Sedge Fen				0 000	27 133	7 409	8 357	6 327
Forested Bog					0 000	15 927	10 002	11 067
Aspen Uplands						0 000	0 377	0 434
Mixedwoods Uplands							0 000	0 141
Conifer Uplands								0 000

TABLE 13 AUTOCORRELATION DISTANCE VALUES FOR SEPTEMBER SIGNATURES

PEATLAND COVER TYPE	AUTOCORRELATION DISTANCE VALUES							
	Treed Fen	Lightly Treed Fen	Shrubby Fen	Sedge Fen	Forested Bog	Aspen Uplands	Mixedwood Uplands	Conifer Uplands
Treed Fen	0 000	1 868	0 680	0 974	0 902	4 038	1 507	4 123
Lightly Treed Fen		0 000	2 217	2 359	0 648	1 365	0 884	5 146
Shrubby Fen			0 000	0 504	1 246	4 005	2 999	4 143
Sedge Fen				0 000	1 206	3 596	3 172	2 075
Forested Bog					0 000	2 513	0 570	2 602
Aspen Uplands						0 000	1 405	6 662
Mixedwoods Uplands							0 000	1 503
Conifer Uplands								0 000

5.3.2 MULTIDATE SIGNATURES

Multidate spectral signatures (Table 14) also demonstrated overlap in radiometric values, although associated ACD values (Table 15) were generally higher than in either series of single date signatures.

Spectral confusion was anticipated for the Treed Fen and Lightly Treed Fen cover types, and was supported by the associated ACD value (Table 15). Spectral confusion of tree covered fens with Shrubby Fens was also anticipated on the basis of respective signatures which varied in the May Band 5 values only. ACD values for Shrubby Fen signatures (Table 15) indicated less than 10% correlation with the other fen signatures (ACD >2.0). This suggested that the May Band 5 values contributed to the uniqueness of this signature. In addition, the ACD values for May signatures for Shrubby Fens were larger than for September signatures (Tables 12 and 13), suggesting potential for better spectral separation using May data.

The Sedge Fen signature was distinct from other signatures for the May radiometric values relative to September values. Consistently high ACD values (Table 15) were indicative of the spectral uniqueness of this signature. The confusion of Sedge Fens with other cover types therefore, was not anticipated when multidate signatures were used in classification.

The Forested Bog signature overlapped considerably with the radiometric values of the Treed Fen signatures (Table

TABLE 14 RADIOMETRIC VALUES OF MULTIDATE SPECTRAL SIGNATURES GENERATED FOR SUPERVISED CLASSIFICATION

	MAY DATA				SEPTEMBER DATA			
	Band 7		Band 5		Band 7		Band 5	
TRAINING AREA	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Treed Fen	70.30	9.50	41.05	1.29	56.38	3.04	31.92	2.89
Lightly Treed Fen	70.42	3.69	41.84	1.81	58.63	3.42	29.93	1.10
Shrubby Fen	73.63	2.80	54.00	3.72	58.31	3.57	34.44	2.09
Sedge Fen	89.59	8.25	72.84	6.76	59.39	8.41	33.18	1.67
Forested Bog	79.37	3.41	39.51	1.75	55.63	3.69	30.27	1.82
Aspen	53.88	4.58	41.57	3.60	65.66	5.76	29.37	1.69
Mixedwoods	55.86	4.25	39.47	3.93	52.85	5.80	27.74	1.77
Upland Conifer	54.35	5.40	38.14	7.20	42.18	4.48	26.76	3.36

TABLE 15 AUTOCORRELATION DISTANCE VALUES FOR RATIDATA SIGNATURES

PEATLAND COVER TYPE	AUTOCORRELATION DISTANCE VALUES							
	Treed Fen	Lightly Treed Fen	Shrubby Fen	Sedge Fen	Forested Bog	Aspen Uplands	Mixedwood Uplands	Conifer Uplands
Treed Fen	0.000	1.778	6.811	15.898	1.330	5.411	2.539	5.879
Lightly Treed Fen		0.000	7.057	19.330	5.815	9.917	1.322	8.061
Shrubby Fen			0.000	5.051	9.021	11.583	9.442	6.900
Sedge Fen				0.000	31.322	14.698	12.615	7.586
Forested Bog					0.000	23.361	12.915	15.754
Aspen Uplands						0.000	1.658	6.548
Mixedwoods Uplands							0.000	1.575
Conifer Uplands								0.000

14). The ACD value of 1.330 (Table 15) indicated the greatest amount of correlation between this signature pair, relative to the other multidate signatures. Similarity in density and species composition of these cover types (Table 3) supported the hypothesis that these two peatland types would be a potential source of spectral confusion in subsequent classification.

Spectral signatures of uplands (aspen, mixedwoods and conifer) demonstrated considerable overlap in May Band 5 and September Band 7 and Band 5 values (Table 14). The relatively low May Band 7 values were attributed to the defoliated condition of the deciduous vegetation, and consequently provided a basis for differentiation between coniferous peatland and deciduous upland cover types. ACD values (Table 15) indicated the greatest potential for spectral confusion between Treed Fens and Mixedwood uplands.

Overall, examination of single date and multidate signatures suggested that spectral signatures may be more specific to cover types when differences in radiometric values are maximized, such that associated ACD values are maximized. This procedure may necessitate construction of multidate signatures consisting of combinations of data unique to each individual signature.

5.3.3 CLASSIFICATIONS

Preliminary analysis of spectral signatures and ACD values indicated that spectral separation of peatland cover

types would be best achieved using multidate data. Of the single date signatures, May data was anticipated to be more useful than September data for separation of cover types. Classification results for Study Area 1 are presented in Table 16.

Visual analysis of the classification results using a color monitor revealed that the use of single date signatures resulted in classification of large proportions of upland regions as either of the five peatland cover types. The classification of these upland regions by single date signatures greatly distorted the geometry and spatial distribution of the peatlands, as previously determined through analysis of enhanced imagery. For the May data, the Treed Fen signature classified most of the upland regions. For the September data, the Forested Bog signature classified the largest proportion of the area, followed by Lightly Treed Fens, Sedge Fens and Treed Fens (Table 16). Overall, September signatures produced the least favorable classification results. This result was in accordance with that predicted based upon examination of radiometric values and ACD values of the respective signatures.

In contrast, multidate signatures were most selective for peatland cover types relative to either series of single date signatures. Multidate classification results, in the form of color themes (Plate 8) portray the geometry and distribution of peatlands as determined by field surveys and examination of enhanced images. In addition, much less of

TABLE 16 - CLASSIFICATION SUMMARY FOR STUDY AREA 1

Peatland Cover Type	% AREA CLASSIFIED		
	Multidate Signatures	May Signatures	September Signatures
Treed Fen	9.5	21.4	10.4
Lightly Treed Fen	4.9	7.4	15.7
Shrubby Fen	6.1	8.0	6.9
Sedge Fen	1.3	1.9	11.5
Forested Bog	3.7	3.0	20.2
% Total Study Area	25.5	41.7	64.7

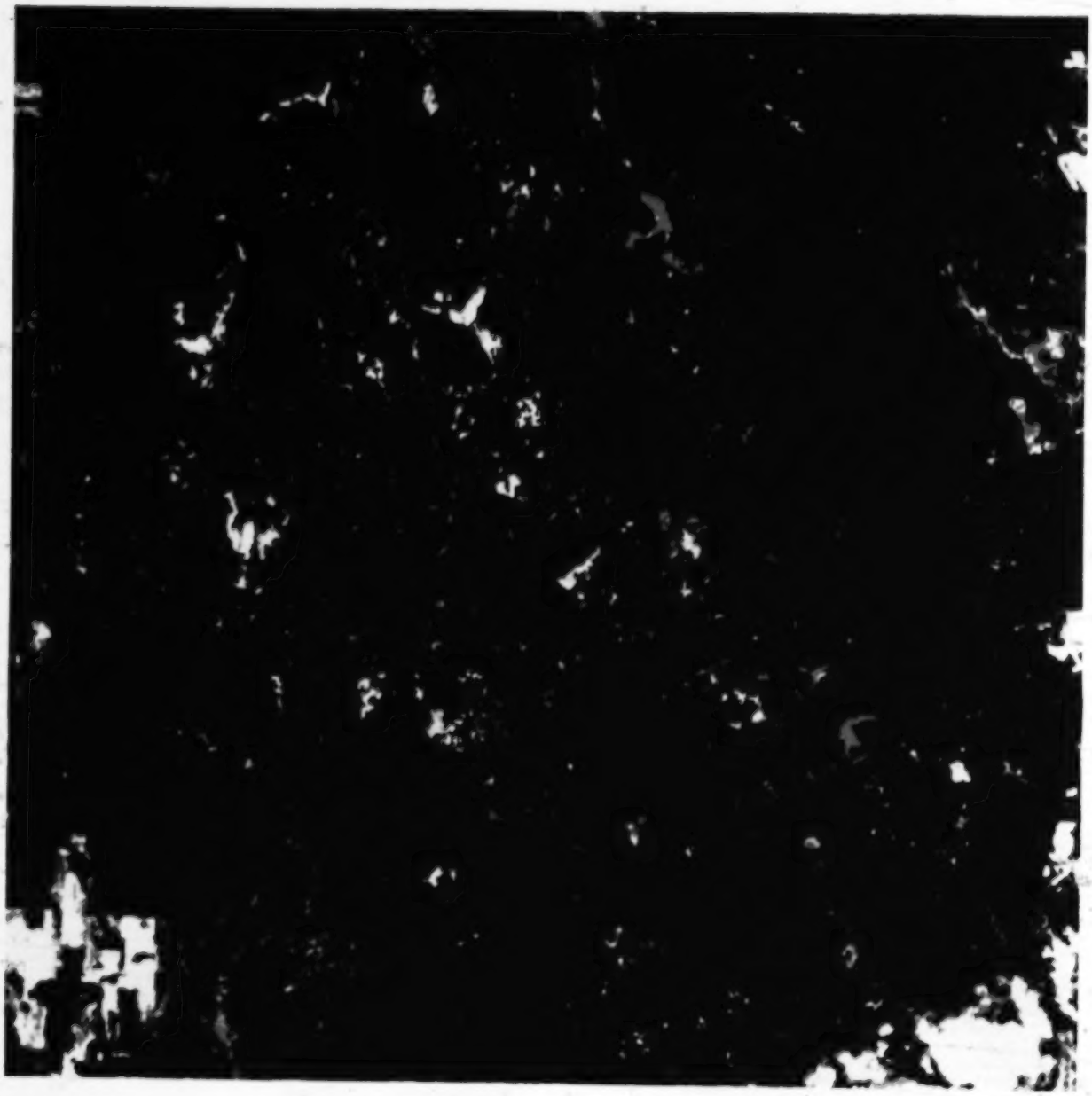


Plate 8 Thematic map of supervised classification results for Study Area 1 using multidate signatures. (Approx. scale 1:140,600).

Legend: Red = Treed Fen
Blue = Lightly Treed Fen
Green = Shrubby Fen
Yellow = Open Sedge Fen
Magenta = Forested Bog

the upland regions were classified, hence the lower total for amount of study area classified with multidate signatures (25.5%) relative to either May (41.7%) or September (64.7%) single date signatures.

5.3.4 COMPATIBILITY ASSESSMENT

Examination of thematic maps, such as that presented in Plate 8, revealed spectral and spatial variability of peatlands as observed in field surveys and depicted on Peatland Inventory Field Maps. This indicated that the central concepts and accompanying range of variability utilized in the Peatland Inventory Field Map unit concepts accommodated this inherent variability. In the Peatland Inventory Field Maps, a "Coniferous Fen" map unit, which included both "Treed Fen" and "Lightly Treed Fen" concepts was utilized. For inventory purposes, therefore, the initial distinction made between Treed Fens and Lightly Treed Fens may not be required.

5.3.4.1 Study Area 1

Compatibility assessments for the results of supervised classification using multidate signatures are presented in Tables 17, 18, 19 and 20 for Study Area 1.

Coniferous Fen map polygons included themes derived from the signatures of Lightly Treed Fens, Treed Fens, Shrubby Fens and Forested Bogs (Table 17). Although the primary theme was that of the Lightly Treed Fen signature, considerable proportions of the polygons were represented as Treed Fen and Shrubby Fen themes. In view of the preliminary analysis of the respective spectral signatures and ACD values (Tables 14 and 15), this result was anticipated. Furthermore, similarity in species composition between Treed Fens and Forested

TABLE 17 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 1: CONIFEROUS FEN

Polygon No	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4° Theme	% Area	% Area Unclassified
1	LTF	40	BF	30	TF	10	0	0	20
2	LTF	20	TF	20	0	0	0	0	60
3	LTF	30	TF	20	BF	10	SB	10	30
4	TF	20	LTF	10	BF	10	SB	10	50
5	LTF	20	TF	10	BF	10	0	0	60
6	TF	10	LTF	10	SB	10	0	0	70
7	LTF	60	BF	20	0	0	0	0	20
8	TF	10	LTF	10	SB	10	0	0	70
9	LTF	30	SB	30	TF	10	BF	10	20
10	LTF	40	SB	30	TF	10	BF	10	10
11	LTF	40	TF	20	BF	20	SB	10	10
12	LTF	40	BF	40	TF	10	0	0	10
13	SB	50	TF	20	0	0	0	0	30
14	TF	30	BF	20	SB	10	0	0	40
15	LTF	30	SB	20	TF	10	BF	10	30

TF = Treed Fen
LTF = Lightly Treed Fen
SB = Shrubby Fen
BF = Forested Bog
0 = No other themes

TABLE 18 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 1 SHRUBBY FEN

Polygon No	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4 Theme	% Area	% Area Unclassified
1	SB	60	0	0	0	0	0	0	40
2	SB	40	TF	20	LTF	10	0	0	30
3	SB	20	TF	10	0	0	0	0	70
4	SB	20	TF	10	W	10	0	0	60
5	SB	60	0	0	0	0	0	0	40
6	SB	20	BF	20	LTF	20	TF	10	30
7	SB	50	0	0	0	0	0	0	50
8	SB	70	SDG	20	0	0	0	0	10
9	BF	10	W	10	0	0	0	0	80
10	SB	20	TF	10	0	0	0	0	70

TF = Treed Fen
LTF = Lightly Treed Fen
SB = Shrubby Fen
SDG = Sedge Fen
BF = Forested Bog
W = Water
0 = No other themes

TABLE 19 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 1 SEDGE FEN

Polygon No	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4° Theme	% Area	% Area Unclassified
1	SDG	70	SB	10	TF	10	0	0	10
2	SDG	60	0	0	0	0	0	0	40
3	SDG	30	SB	30	TF	10	0	0	30

TF = Treed Fen
SB = Shrubby Fen
SDG = Sedge Fen
0 = No other themes

TABLE 20 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 1 FORESTED BOG

Polygon No	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4 Theme	% Area	% Area Unclassified
1	BF	80	LTF	20	0	0	0	0	0
2	TF	10	LTF	10	0	0	0	0	80
3	BF	90	0	0	0	0	0	0	10
4	BF	40	TF	20	LTF	10	0	0	30
5	BF	90	0	0	0	0	0	0	10
6	BF	90	0	0	0	0	0	0	10
7	BF	80	0	0	0	0	0	0	20
8	BF	90	0	0	0	0	0	0	10
9	BF	90	0	0	0	0	0	0	10
10	BF	70	LTF	10	0	0	0	0	20
11	BF	60	TF	20	0	0	0	0	20
12	BF	40	LTF	20	0	0	0	0	40
13	TF	50	BF	30	SB	10	0	0	10
14	BF	70	TF	10	SB	10	0	0	10
15	BF	30	TF	20	0	0	0	0	50

TF = Treed Fen
LTF = Lightly Treed Fen
SB = Shrubby Fen
BF = Forested Bog
0 = No other themes

Bogs, and the potential occurrence of boundary pixels likely contributed to the variability in spectral characteristics of these cover types. Polygon areas that remained unclassified ranged from a low of 10% to a high of 70%, with most between 10% to 30% unclassified. This is attributed to the spectral signatures utilized in the classification not being representative of all variations in Coniferous Fen cover types.

Shrubby Fen polygons were represented by the Shrubby Fen theme being dominant in 9 out of 10 polygons examined (Table 18). Secondary themes consisted of Treed Fen, Forested Bog, Sedge Fen or Water. This result is attributed to the gradational vegetation pattern associated with fen complexes in the study region (Plate 1). In addition, associated spectral signatures and ACD values (Tables 14 and 15) indicated the potential for spectral confusion of these cover types. Furthermore, the gradational pattern of vegetation associations contributes to the occurrence of boundary pixels that may remain unclassified. As observed in the Coniferous Fen polygons, relatively large proportions of Shrubby Fen polygons remained unclassified. This indicated that not all inherent spectral characteristics of Shrubby Fens were described by the signatures.

Of the three Sedge Fens examined, all were classified by the Sedge Fen signature as the prevalent theme (Table 19). Treed Fen and Shrubby Fen themes,

however, occurred within two of these polygons, suggesting the likelihood of association of these cover types.

Treed Fen, Lightly Treed Fen and Shrubby Fen themes generally represented less than 20% of the area of Forested Bog polygons (Table 20). This could be attributed to the spectral and spatial variability of respective cover types. Unclassified areas occurred less frequently in Forested Bog polygons than in Coniferous Fen and Shrubby Fen polygons (Tables 17 and 18). This may be attributed to the consistent density and spectral homogeneity of the black spruce cover of Forested Bogs.

5.3.4.2 Study Area 2

Preliminary evaluation of the thematic map for Study Area 2 indicated that signature extension was of limited utility. For the peatland polygons examined, large areas often remained unclassified. Compatibility assessments for signature extension results are presented in Tables 21, 22, 23 and 24.

Coniferous Fen polygons were represented by Forested Bog, Treed Fen, Lightly Treed Fen and Shrubby Fen themes (Table 21). As observed in Study Area 1, this result demonstrated the spatial and spectral complexity encompassed by this Peatland Inventory Field Map unit concept. Treed Fens and Lightly Treed Fens were most prevalent as primary or secondary themes, although they individually represented only 10% to 20% of the polygon

TABLE 21 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 2 CONIFEROUS FEN

Polygon No	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4° Theme	% Area	% Area Unclassified
1	BF	20	LTF	10	TF	10	SB	10	50
2	TF	10	LTF	10	SB	10	BF	10	60
3	BF	40	TF	10	LTF	10	SB	10	30
4	TF	10	LTF	10	SB	10	BF	10	60
5	SB	60	TF	10	0	0	0	0	30
6	SB	40	TF	10	LTF	10	BF	10	30
7	TF	10	LTF	10	0	0	0	0	80
8	LTF	20	TF	10	BF	10	0	0	60
9	TF	10	LTF	10	BF	10	SB	10	60
10	TF	20	LTF	20	SB	10	0	0	50

TF = Treed Fen
LTF = Lightly Treed Fen
SB = Shrubby Fen
BF = Forested Bog
0 = No other themes

TABLE 22 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 2 SHRUBBY FEN

Polygon No	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4° Theme	% Area	% Area Unclassified
1	SB	60	TF	10	SDG	10	0	0	20
2	SB	10	0	0	0	0	0	0	90
3	SB	20	TF	20	0	0	0	0	60
4	SB	30	TF	10	LTF	10	0	0	50
5	SB	20	TF	10	LTF	10	0	0	60
6	SB	30	BF	20	TF	10	LTF	10	30

TF = Treed Fen
LTF = Lightly Treed Fen
SB = Shrubby Fen
BF = Forested Bog
SDG = Sedge Fen
0 = No other themes

TABLE 23 COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 2: SEDGE FEN

Polygon No.	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4 Theme	% Area	% Area Unclassified
1	SDG	30	SB	20	0	0	0	0	50
2	SDG	20	SB	20	0	0	0	0	60
3	SB	10	0	0	0	0	0	0	90

SDG = Sedge Fen
SB = Shrubby Fen
0 = No other themes

TABLE 24. COMPATIBILITY ASSESSMENT OF MULTIDATE SUPERVISED CLASSIFICATION OF STUDY AREA 2: FORESTED BOG

Polygon No.	1° Theme	% Area	2° Theme	% Area	3° Theme	% Area	4° Theme	% Area	% Area Unclassified
1	BF	40	TF	10	SB	10	0	0	40
2	BF	50	TF	10	0	0	0	0	40
3	BF	70	TF	10	0	0	0	0	20
4	BF	20	TF	10	LTF	10	0	0	60
5	BF	30	TF	20	0	0	0	0	50
6	BF	40	TF	10	LTF	10	0	0	40
7	SB	30	TF	10	0	0	0	0	60
8	BF	10	TF	10	LTF	10	SB	10	60
9	BF	10	TF	10	LTF	10	0	0	70
10	BF	60	0	0	0	0	0	0	40
11	BF	20	TF	10	LTF	10	0	0	60
12	BF	60	TF	10	0	0	0	0	30
13	BF	40	TF	10	0	0	0	0	50
14	BF	40	TF	30	LTF	10	0	0	20
15	BF	10	SB	10	LTF	10	0	0	70

TF = Treed Fen
LTF = Lightly Treed Fen
SB = Shrubby Fen
BF = Forested Bog
0 = No other themes.

areas. The relatively large areas remaining unclassified indicated that the spectral characteristics of the respective polygons were not described by the signatures utilized.

Shrubby Fen polygons consisted of 10% to 60% coverage by the Shrubby Fen theme (Table 22). Secondary and tertiary themes of Treed Fen and Forested Bog indicated the heterogeneity of vegetation cover associated with fen complexes.

Sedge Fens were very poorly depicted by themes (Table 23). This may be due to their association with streams in this study area, resulting in narrow, linear landscape units prone to inclusion within boundary pixels.

Forested Bog polygons were identified primarily by the Forested Bog theme in 14 out of the 15 polygons examined (Table 24). Secondary themes included those of Treed Fen, Lightly Treed Fen and Shrubby Fen signatures, indicative of the spatial and spectral variations of these cover types.

The ability to identify Forested Bogs on the basis of their multidate spectral signatures was demonstrated for both study areas, and confirmed the hypothesis derived from the preliminary analysis of spectral signatures and associated ACD values (Tables 14 and 15). For homogeneous areas, relatively high classification accuracies have been

reported (Beaubien 1979, Pala and Jano 1981), but spatially complex areas have presented difficulties in classification (Barnard *et al.* 1981, Pitblado and Amiro 1982).

Overlap in the spectral signatures representing Fen cover types indicated potential difficulty in their spectral separation through supervised classification. Spectral heterogeneity and spatial variability of fens was demonstrated in the thematic maps produced for each study area. Furthermore, preliminary analysis of associated ACD values suggested that spectral confusion would occur in subsequent classification of Fen cover types.

Within the study areas classified, peatland polygon areas that remained unclassified were not described by the parameters of the peatland signatures generated. This could be the result of spectrally unique boundary pixels occurring in transition areas due to spatial complexity of peatlands, or to spectral variability in cover types attributed to density, height and effects of sun angle. The latter variables have been previously described by Hoffer (1978), Beaubien (1979) and Dana (1982).

The inability to obtain representative spectral signatures in heterogenous environments is often reported in studies utilizing classification procedures (Table 2). In the application of supervised classification, a major problem involves definition of training areas that are representative of all significant variations of spectral response for cover types of interest (Hoffer and Swain

1980). In wildland regions, inherent spectral complexity manifests an additional difficulty in the location of training areas (Driscoll *et al.* 1974, Fleming *et al.* 1975, Lee 1980, Barnard *et al.* 1981, Pitblado and Amiro 1982). Furthermore, an analyst can never know beforehand if a training area will adequately represent the spectral variation of a given cover type (Campbell 1981).

An alternate method of obtaining spectral signatures that are representative of inherent spectral variability involves continuous redefinition and partitioning of training area sites. This practice, although potentially useful, violates the objective of performing a large area inventory efficiently and cost-effectively using LANDSAT MSS data, because continuous refinement of spectral signatures requires accurate field data. If the quality and quantity of field information to implement this practice are available, it is likely that LANDSAT MSS classifications of these areas would not be required.

6. SUMMARY AND CONCLUSIONS

Three methods of digital image analysis (image enhancement, unsupervised classification and supervised classification) were applied to LANDSAT-2 MSS imagery of the Athabasca-Calling Lake region to determine the spectral separability of peatland types.

Image enhancement facilitated preliminary stratification of the study region through visual interpretation. Multidate data (May Bands 7 and 4 and September Band 7) provided optimal contrast between peatland and upland cover types. May imagery (Bands 7, 5 and 4) was superior to September imagery for the delineation of broad cover classes.

Unsupervised classification identified regions within the study areas that were spectrally homogeneous, but the resultant spectral classes were not physiognomically unique. May imagery produced the greatest number of spectral classes, indicative of greater variability between spectral characteristics of ground cover for this date of imagery, relative to September. In the attempt to bias a clustering algorithm to generate spectral signatures representative of peatlands, the complexity of spectral and spatial characteristics of the region was demonstrated. This inherent complexity indicated that subsequent supervised classification procedures would be limited by the heterogeneity of the study area.

Spectral signatures generated for peatland and upland cover types demonstrated considerable overlap in radiometric values. Autocorrelation distance values further indicated the potential for spectral confusion of peatlands and uplands during supervised classification. Multidate signatures demonstrated a greater selectivity for peatlands than either May or September signatures. Of the peatland cover types represented on thematic maps, Forested Bogs and Sedge Fens were most often correctly located in accordance with respective map units portrayed on the Peatland Inventory Field Maps used as verification data. This was attributed to their homogeneous vegetative cover, relative to that of Treed Fens, Lightly Treed Fens and Shrubby Fens.

The spectral and spatial heterogeneity of vegetation cover types precluded the utility of signature extension as a method of large area inventory. Furthermore, the occurence of relatively large proportions of unclassified peatland regions within the signature extension test segment indicated that the spectral signatures generated were not representative of all variations in spectral response of peatlands. During field surveys, variability of peatland types may be accommodated through incorporation of an allowed range of variability in the definition of map unit concepts. In map unit concepts based on spectral signatures however, the inclusion of an allowed range of variability translates into two potential problems:

1. Large standard deviations associated with mean radiometric values increase the potential for spectral confusion of ground cover types; and
2. Training areas that are representative of all significant variations of a particular cover type must be identified.

In supervised classification the primary objective involves selection of specific spectral responses through definition of representative training areas. Inherent variability and complexity of cover types complicate this procedure such that a tradeoff between the specificity of map units and the amount of area that is correctly classified must be realized. For purposes of large area inventory, therefore, both the limitations and the utility of satellite data should be considered. Limitations involve the spectral, spatial and temporal resolutions, whereas utility involves the multispectral and multidate nature of the data.

The degree to which LANDSAT MSS digital data can be applied to a peatland inventory is therefore dependent upon the level of detail required according to inventory objectives, the spectral separability of peatlands and the analysis procedures utilized. Furthermore, the compatibility of the peatland classification system utilized and the results of digital classifications must be recognized. Although the Wetland Classification System (Tarnocai 1980) was adopted by the Peatland Inventory Pilot Project, LANDSAT

MSS data contributed spectral information potentially useful at the third level (Type level) of the classification hierarchy. The utility of LANDSAT MSS data was subsequently determined by the spectral separability of peatland types. At the primary and secondary levels of the classification system (Class and Form) requirements for information on genesis, surface morphology and water chemistry necessitated site-specific sampling.

In a peatland inventory, the requirements for site-specific information predispose the utility of multistage inventory procedures. In view of the spatial and spectral complexity of the areas studied, LANDSAT MSS data may be of greatest utility when incorporated into a multistage peatland inventory whereby:

1. Enhanced color composite images are used for preliminary stratification of the study region.

2. Unsupervised classification is used to determine regions of greatest spectral homogeneity or heterogeneity to be used as a basis for field sampling.

3. Supervised classification is used to locate and quantify the areal extent of spectrally separable peatland types.

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8. APPENDICES

APPENDIX 1

APPENDIX 1.1

RESIDUALS OF POLYNOMIAL TRANSFORMATION COEFFICIENTS FOR GEOMETRIC CORRECTION OF MAY DATA

GCP No.	Slave Pixel	Slave Line	Master Pixel Actual	Master Pixel Est.	Master Pixel Residual	Master Line Actual	Master Line Est	Master Line Residual
1	743	910	316755	316774.5	-19.5	6117300	6117286.5	13.5
2	756	1076	313450	313949.9	-44.9	6104375	6104376.5	- 1.5
3	1046	1086	329075	329029.4	45.6	6098550	6098615.5	-65.5
4	773	1200	311475	311441.6	33.4	6094625	6094607.5	17.5
5	1252	1123	339325	339346.3	-21.3	6092250	6092238.5	11.5
6	1199	1220	334125	334133.8	- 8.7	6085750	6085739.0	11.0
7	928	1424	314525	314493.3	31.8	6074850	6074818.5	31.5
8	1067	1399	322650	322654.6	- 4.6	6074325	6074334.0	- 9.0
9	1256	1398	332975	332959.4	15.6	6071175	6071154.0	21.0
10	929	1588	310625	310609.0	16.0	6062250	6062269.0	-19.0
11	1228	1709	323950	323967.3	-17.3	6047875	6047870.0	5.0
12	989	1744	310100	310126.2	-26.2	6049300	6049313.5	-13.5

Standard Error of Pixel Estimate = 24.48 m

Standard Error of Line Estimate = 22.23 m

APPENDIX 1.2

RESIDUALS OF POLYNOMIAL TRANSFORMATION COEFFICIENTS FOR GEOMETRIC CORRECTION OF SEPTEMBER DATA

GCP No.	Slave Pixel	Slave Line	Master Pixel Actual	Master Pixel Est.	Master Pixel Residual	Master Line Actual	Master Line Est.	Master Line Residual
1	584	1470	448	448.3	-0.3	928	928.7	-0.7
2	585	1679	348	347.6	0.4	1249	1248.1	0.9
3	623	1086	677	677.7	-0.7	356	355.8	0.2
4	925	1260	921	921.1	-0.1	725	725.7	-0.7
5	1320	1062	1446	1446.8	-0.8	560	559.7	0.3
6	1378	1330	1380	1379.3	0.7	989	989.0	0.0
7	1139	1573	1001	1001.2	-0.2	1277	1277.5	-0.5
8	738	1458	622	621.5	0.5	963	963.5	-0.5
9	945	1717	720	720.3	-0.3	1431	1430.4	0.6
10	941	809	1159	1158.2	0.8	43	42.6	0.4

Standard Error of Pixel Estimate = 0.49 pixel (24.5 m)

Standard Error of Line Estimate = 0.48 pixel (24.0 m)

APPENDIX 2

APPENDIX 2.1

HISTOGRAM INTERVAL ASSIGNMENTS UTILIZED IN PIECE-WISE STRETCH OF STUDY AREA 1

MAY DATA

Band 7

Histogram Value	Piece-wise Assignment
0	0
10	1
40	10
90	254
255	255

Band 5

Histogram Value	Piece-wise Assignment
0	0
20	1
70	254
255	255

Band 4

Histogram Value	Piece-wise Assignment
0	0
20	1
50	220
51	254
255	255

SEPTEMBER DATA

Band 7

Histogram Value	Piece-wise Assignment
0	0
30	1
80	254
255	255

Band 5

Histogram Value	Piece-wise Assignment
0	0
15	1
60	254
255	255

Band 4

Histogram Value	Piece-wise Assignment
0	0
20	1
40	254
255	255

APPENDIX 2.2

HISTOGRAM INTERVAL ASSIGNMENTS UTILIZED IN PIECE-WISE STRETCH OF STUDY AREA 2

* MAY DATA

Band 7

Histogram Value	Piece-wise Assignment
0	0
35	1
80	220
90	254
255	255

Band 5

Histogram Value	Piece-wise Assignment
0	0
20	1
75	254
255	255

Band 4

Histogram Value	Piece-wise Assignment
0	0
20	1
60	254
255	255

* SEPTEMBER DATA

Band 7

Histogram Value	Piece-wise Assignment
0	0
95	254
255	255

Band 5

Histogram Value	Piece-wise Assignment
0	0
15	1
60	254
255	255

Band 4

Histogram Value	Piece-wise Assignment
0	0
20	1
45	254
255	255

APPENDIX 3

APPENDIX 3. GLOSSARY OF TERMS

(after Bernstein (1978) and Moik (1980))

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affine transformation: a geometric transformation of digital data which includes rotation, displacement, scaling and skewing.

boundary pixel: a pixel whose radiometric value is a composite of the reflectance characteristics of several different terrain components.

classification: the process of assigning individual pixels of a multispectral image to categories, generally on the basis of spectral-reflectance characteristics.

control points: recognizable geographic features or landmarks that relate an image with the object.

cubic convolution: a cubic spline approximation to the theoretically perfect sinc(x) resampling function. It uses a 16-point (4x4) neighborhood of pixels as input to compute the value of the output pixel.

geometric correction: the removal of sensor, platform or scene induced geometric errors such that the data conform to a desired projection. This involves the creation of a new digital image by resampling the input digital image.

maximum likelihood decision rule: decision rule that treats the pattern independently and assigns a pattern or feature vector c to that class S_i that most probably gave rise to pattern or feature vector c; that is, such that the conditional probability density of c given S_i, $p(c|S_i)$, is highest.

pixel: a pair whose first member is a resolution cell and whose second member is the grey tone assigned by the digital image to that resolution cell. Sometimes pixel is used in a sense which is synonomous with resolution cell and other times synonomous with the grey tone.

training area: group of pixels representative of a known ground cover that are used to estimate the class conditional probability distributions from which the decision rule may be constructed.